Documentation and Testing of the WEAP Model for the Rio Grande/Bravo Basin

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Abstract

The Rio Grande/Bravo basin is located in North America between two riparian nations, the United States (US) and Mexico. This river is currently considered a water scarce area with less then 500 m^3 per person per year of water available. Throughout the decades there has been a lot of population growth in the basin, with population expected to double over the next three decades.

The Physical Assessment Project promotes regional cooperation between the US and Mexico to work towards more effectively managing the Rio Grande/Bravo's resources. This report falls under Task 3 of the project by documenting and testing the basin-wide model constructed using WEAP software.

The documentation of the model addresses all of the inputs for demands and supplies for the river. The model is also set up to include operating polices of the different countries and how they each allocate water to their demands. The supplies in the model include tributary inflows, as well as reservoir and groundwater storage.

This report is the first of many testing phases. The two items that were evaluated here, by comparing them against historical records, were the reservoir storage volumes and the streamflow for six IBWC gages. This testing demonstrated that the model has the right logic and flow pattern, however adjustments need to be made to the reservoir releases in order to fully represent the existing system.

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Introduction

The Rio Grande/Bravo basin is located in North America along the boarder of the United States (US) and Mexico. This region is considered one of the most water stressed areas of the world with less then 500 m^3 of water available per person per year as of 2001 (Figure 1). The water stress indexes are shown in Table 1.

Table 1: Water Stress Indexes (Giordono and Wolf 2002)

Term	Amount of Water	Results
Relative sufficiency	> 1700 m3 /person/year	
Water stress	< 1700 m3 /person/year	intermittent, localised shortages of freshwater
Water scarcity	< 1000 m3 /person/year	chronic and widespread freshwater problems
Absolute scarcity	< 500 m3 /person/year	

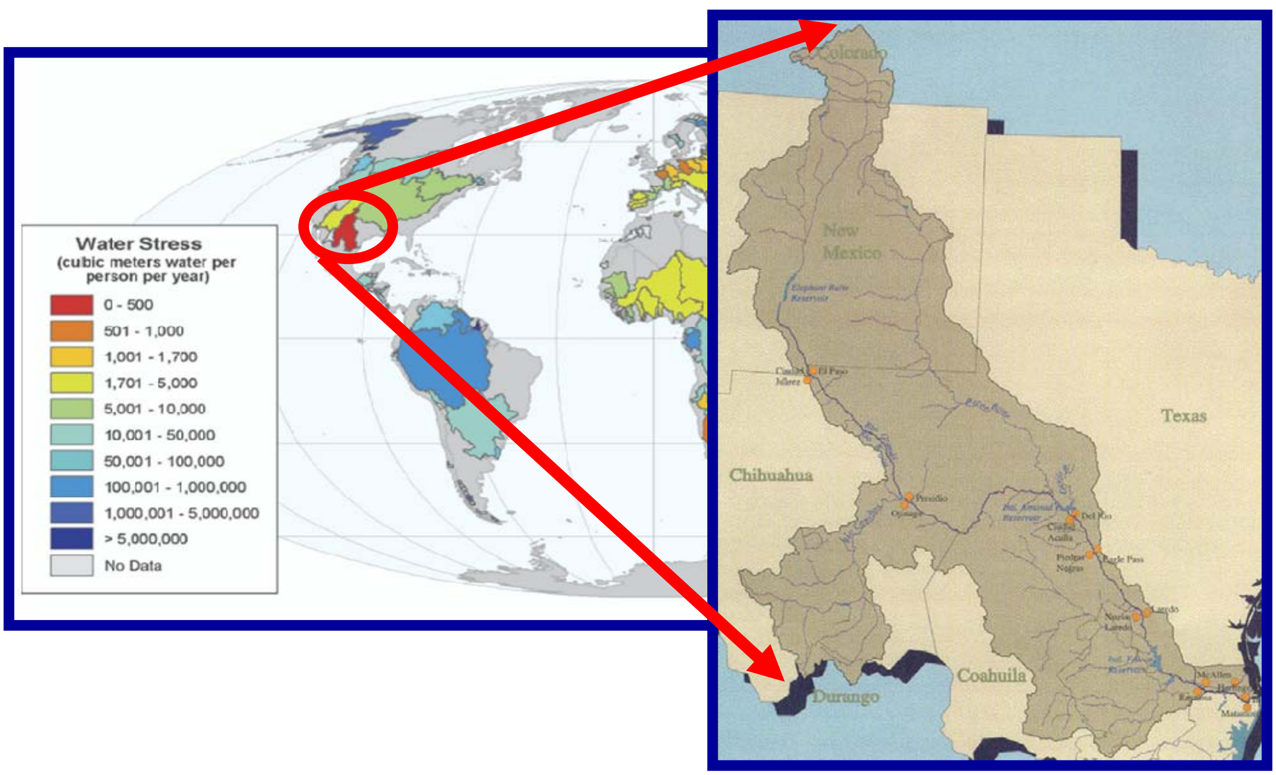


Figure 1: Global Water Stress and location of the Rio Grande basin
(Source: Stress - www.transboundarywaters.orst.edu; Rio Grande diagram - www.rioweb.org)

This river forms a bi-national border and international agreements have been in place since the formation of the International Boundary and Water Commission (IBWC) in 1889. The 1944 Water Treaty between

the US and Mexico established water allocations for both the Colorado River and the Rio Grande/Bravo. The treaty states, generally, that 432.7 million cubic meters (MCM) (350,000 acre-feet) of water must be provided by Mexico as an annual average over a five year period below the confluence with the Rio Conchos (IBWC 1944).

The headwaters of the Rio Grande/Bravo are located in Colorado and the river flows southeast towards the Gulf of Mexico as shown in Figure 2 encompassing a total area of 555,000 km^2 with 228,000 km^2 in Mexico and 327,000 km^2 in the US.

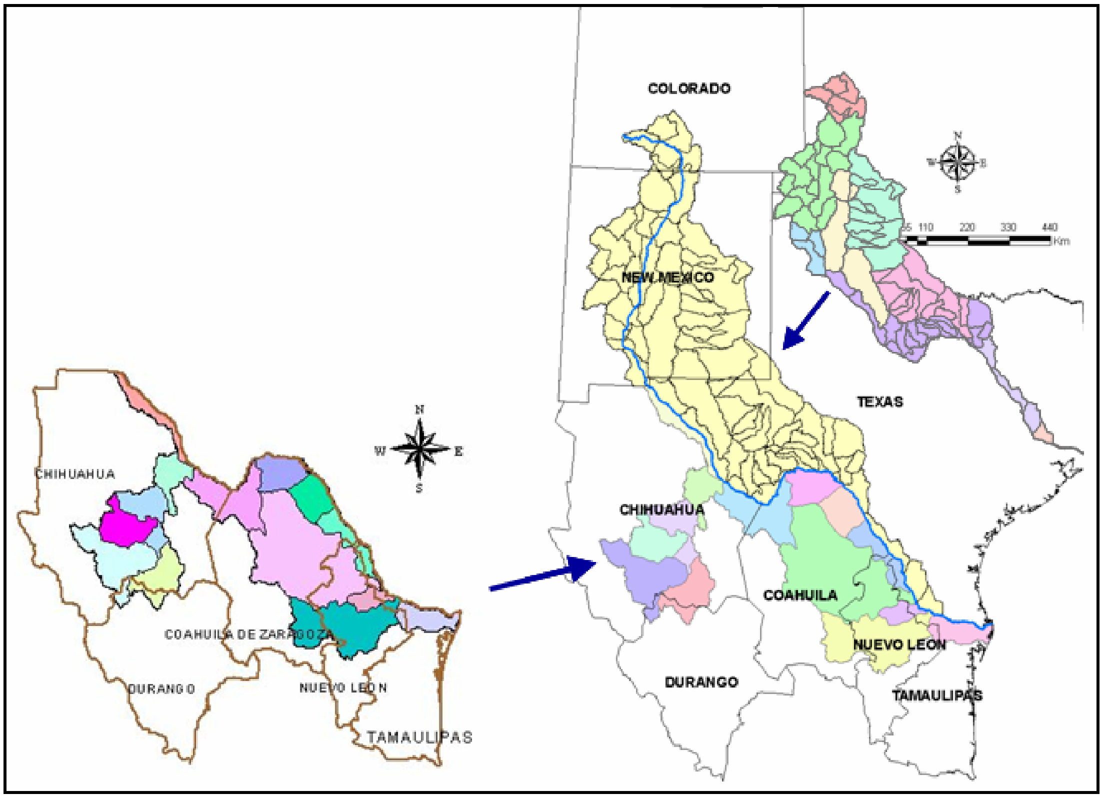


Figure 2: GIS Map of the Rio Grande/Bravo Basin (McKinney et al. 2006)

This large river basin is highly stressed by the current population needs and will continue to be stressed because the population (9.73 million in December 2001) is expected to double by 2030 (CRWR 2006a).

This report describes the basin-wide Water Evaluation and Planning System (WEAP) model (SEI 2006) that was constructed to help evaluate stakeholder driven scenarios to more effectively manage these highly stressed water resources. This report also describes the background of the overall project, the WEAP software used for the basin-wide model, documenting the current model inputs, model testing, and then future work.

Physical Assessment Project Description

The work for this project is conducted in conjunction with the Physical Assessment Project, promoting regional cooperation and policy development between and among the US and Mexico. Technical assistance is being provided by both Mexican and US experts and institutional counterparts; the project's steering committee , comprised of universities, non-governmental organizations, and government research institutes in the US and Mexico, is shown in Figure 3.

The overall objective of the Physical Assessment Project is to "examine the hydro-physical opportunities for expanding the beneficial uses of the fixed water supply in the Rio Grande/Bravo to better satisfy an array of possible water management objectives, including meeting currently unmet needs in all sectors (agricultural, urban, and environmental), all segments, and both nations." (CRWR 2006a) The project website address is: www.riogrande-riobravo.org.

Task 3, Construct a Reconnaissance-Level Model at the Basin-Wide Scale, of the Physical Assessment Project is the main focus of this report. In particular, subtasks 3.1, Assembling the WEAP Tool, and 3.3, Refining the WEAP Model (CRWR 2006b). The purpose of this report is to document the current data inputs into the model and initial testing of the model.

Figure 3: Physical Assessment Project Steering Committee (CRWR 2006a)

WEAP Software

The software used for modeling the water management system of the Rio Grande/Bravo is Water Evaluation and Planning System (WEAP) software developed by the Stockholm Environment Institute (SEI 2006). The license fee for this software is waived for academic, governmental, and other non-profit organizations in developing countries, including Mexico. Some of the highlights for using this software are that it has an integrated approach, easily involves stakeholders, uses a priority-drive water balance methodology, and has ways to implement different scenarios in a friendly interface (Table 2). WEAP software also uses a graphic user interface that imports graphic files from other software systems to help create models, such as shapefiles from geographic information systems (GIS). The WEAP model schematic generated for the Rio Grande/Bravo is shown in Figure 4.

The Physical Assessment Project team has developed WEAP tutorials in Spanish and English for the Rio Conchos Subbasin (Nicolau del Roure and McKinney 2005). These exercises are easy to use, step by step instructions addressing how to construct a WEAP model for this particular subbasin.

Table 2: WEAP Software Highlights (WEAP 2006)

Integrated Approach	Unique approach for conducting integrated water resources planning assessments
Stakeholder Process	Transparent structure facilitates engagement of diverse stakeholders in an open process
Water Balance	A database maintains water demand and supply information to drive mass balance model on a link-node architecture
Simulation Based	Calculates water demand, supply, runoff, infiltration, crop requirements, flows, and storage, and pollution generation, treatment, discharge and in stream water quality under varying hydrologic and policy scenarios
Policy Scenarios	Evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems
User-friendly Interface	Graphical drag-and-drop GIS-based interface with flexible model output as maps, charts and tables

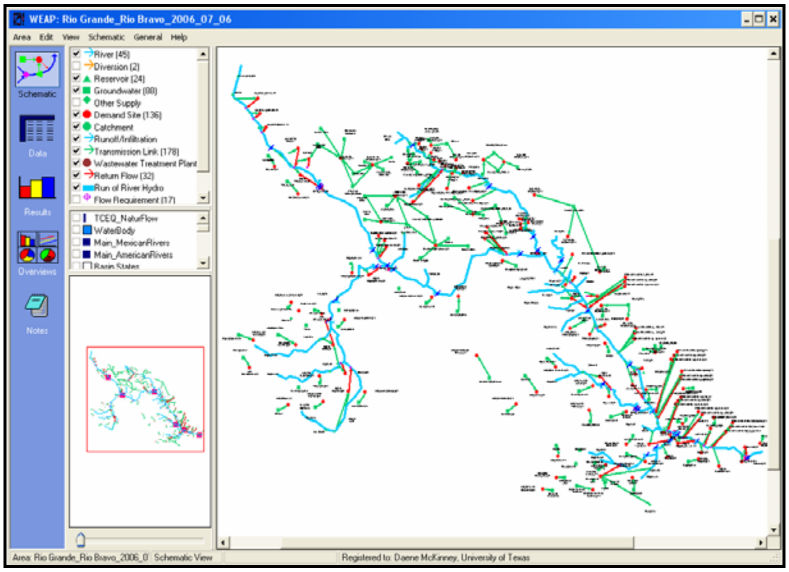


Figure 4: WEAP Model for the Rio Grande/Bravo Schematic

The WEAP model has three main screens utilized in this project. The first screen is the Schematic View as shown in Figure 4. This screen enables the user to add nodes, demand sites, transmission links, etc. The second screen is the Data View as shown in Figure 5. There are six main branches to the Data View including Key Assumptions, Demand Sites, Hydrology, Supply and Resources, Water Quality and Other Assumptions. The project is currently working with three of the six branches, Key Assumptions, Demand Sites and Supply and Resources. Each of these areas is further broken down into smaller branches. First, the branches for Key Assumptions are shown in Figure 6 and are currently being used for reservoir operating policies, demand priority levels, treaty requirements and the Texas Watermaster logic. Second, every Demand Site has its own branch as illustrated in Figure 7. Lastly, Supply and Resources is divided into five sub-branches; Linking Demands and Supply, River, Groundwater, Local Reservoirs, and Return Flows as shown in Figure 8. The last screen view used is for results. This screen is used after the model has been run and displays the results graphically or tabular. The model also has a feature where the user can export the results to a comma separated variable (CSV) file or a spreadsheet file.

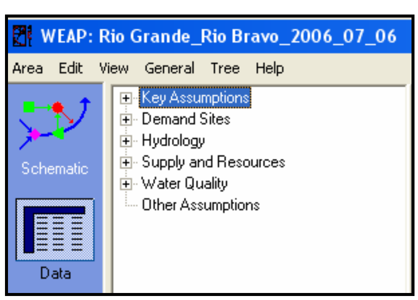


Figure 5: Data View for WEAP

Figure 6: Key Assumptions Branches

Figure 7: Demand Site Branches

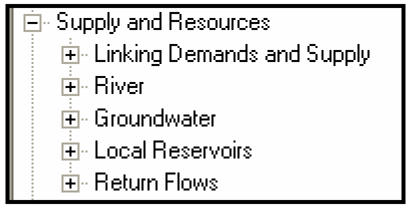


Figure 8: Supply and Resources Branches

Model Construction

Model Subbasins

The model for the Rio Grande/Bravo basin (Appendix B, Figure 27) starts at the USGS San Marcial gauge above Elephant Butte reservoir in New Mexico and ends at the Gulf of Mexico. The basin is divided into five sections; Upper, Rio Conchos, Pecos, Middle and Lower subbasins. The Upper subbasin includes the main stem of the Rio Grande/Bravo starting at Elephant Butte Reservoir and ends above the confluence of the Rio Conchos (Appendix B, Figure 28). This section of the basin is located in the US states of New Mexico and Texas and the Mexican state of Chihuahua. The two major reservoirs are Elephant Butte and Caballo.

The Rio Conchos subbasin contains the Rio Conchos and its main tributaries which lie in the Mexican state of Chihuahua and a small portion of Durango State (Appendix B, Figure 29). This section is the key for Mexico to meet its obligations under the 1944 Treaty. The two main tributaries for the Rio Conchos are the Rio Florido and the Rio San Pedro. The four main reservoirs in this subbasin are San Gabriel, La Boquillla, Francisco Madero and Luis L. Leon.

The Pecos River subbasin is located in the US states of New Mexico and Texas (Appendix B, Figure 31). So far the Pecos River is only considered from the confluence with the Rio Grande up to the Texas – New Mexico border above the Red Bluff reservoir, the main reservoir in this subbasin.

The Middle Rio Grande/Bravo subbasin extends from the confluence of the Rio Conchos to the inflow of Amistad International Dam (Appendix B, Figure 30) and forms the border between the US state of Texas and the Mexican states of Chihuahua and Coahuila.

The Lower Rio Grande/Bravo subbasin extends from the inflow of Amistad International Dam to the inflow into the Gulf of Mexico and also forms the border between Texas and the Mexican states of Coahuila, Nuevo Leon and Tamaulipas (Appendix B, Figure 32). There are four reservoirs of interest in this section including, Amistad International Dam, Falcon International Dam, V. Carranza, and El Cuchillo. The V. Carranza reservoir is located on the Rio Salado tributary and El Cuchillo reservoir is located on the Rio

San Juan, the only major tributary on the Rio Grande/Bravo below the Pecos River.

Demand Sites

Currently, there are 136 demand sites included in the model. These demand sites include water use for municipalities, irrigation, mining, industrial and other uses. For each demand site, there are seven characteristic tabs for entering information in the model: Water Use, Loss and Reuse, Demand Management, Water Quality, Cost, Priority, and Advanced, as shown in Figure 9. The project is currently working with the data available for the Water Use and Priority tabs.

The Priority tab assigns each demand site a priority level ranging from 1 to 99. Priority level 99 is used for reservoirs and levels 6 through 98 are unassigned. Level 1 is the highest demand priority for water in the system and is assigned to all municipal users. Mexican irrigation demands are currently assigned priority levels 2 through 4 and level 5 represents the 1944 Treaty requirements (Table 3). US irrigation demands are currently being adjusted to reflect the breakdown shown in Table 4. The model uses these priority levels when allocating water for the demand sites. The model will deliver water to all the level ones priority sites and, if there is any water remaining in the system, it will then deliver water to the remaining priority levels. An optional allocation rule is included in the Key Assumptions and was developed by Mexican Institute of Water Technology (IMTA) for estimating allocations to the Mexican irrigation districts based on available reservoir storage.

Table 3: Assigned Priority Levels for Mexican Demands

Demand Type	Priority Level
Municipal	1
Irrigation - For areas in the upper watershed	2
Irrigation - For areas in the middle watershed	3
Irrigation - For areas in the lower watershed	4
Treaty	5
Reservoir	99

Table 4: Priority Levels for US Demands

Demand Type	Priority Level
Municipal	1
Type A Irrigation	2
Type B Irrigation	3
Other	4
Treaty	5
Reservoir	99

The Water Use Tab four has four Sub-tabs: Annual Activity Level, Annual Water Use Rate, Monthly

Variation, and Consumption (Figure 9). Currently, two of these fields, Annual Water Use Rate and Monthly Variation, are being used by the project. Monthly variation is entered using the monthly time-series wizard that creates a monthly percentage water use from the total annual water use rate. This way the demands are not all withdrawn in one month but spread out throughout the year. Data for some of the demand sites has been entered for the Consumption tab as a percentage and reflects the portion of water that may return to the river. In the Lower Subbasin there is little to no return flow to the Rio Grande/Bravo due to the hydrological scheme that distributes the water to the Laguna Madre in both Texas and Tamaulipas rather then the Rio Grande/Bravo (Patiño 2006).

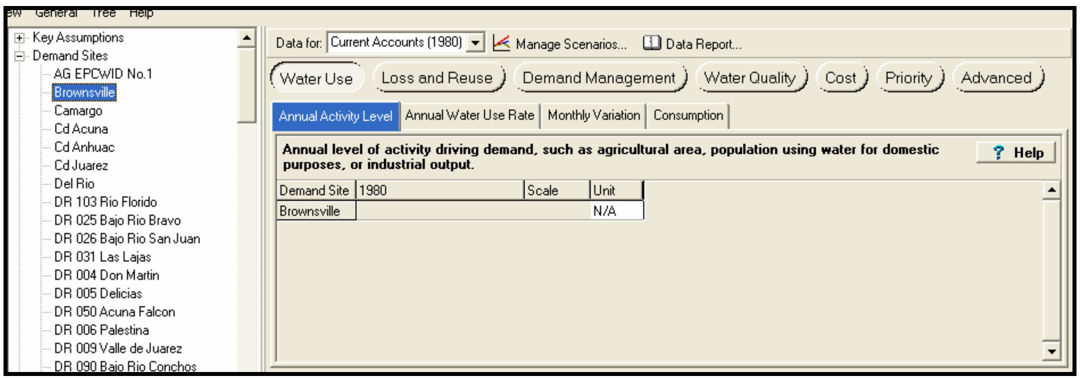


Figure 9: Water Use Tab Screen Capture for Brownsville Demand Site

I. Mexican Municipalities

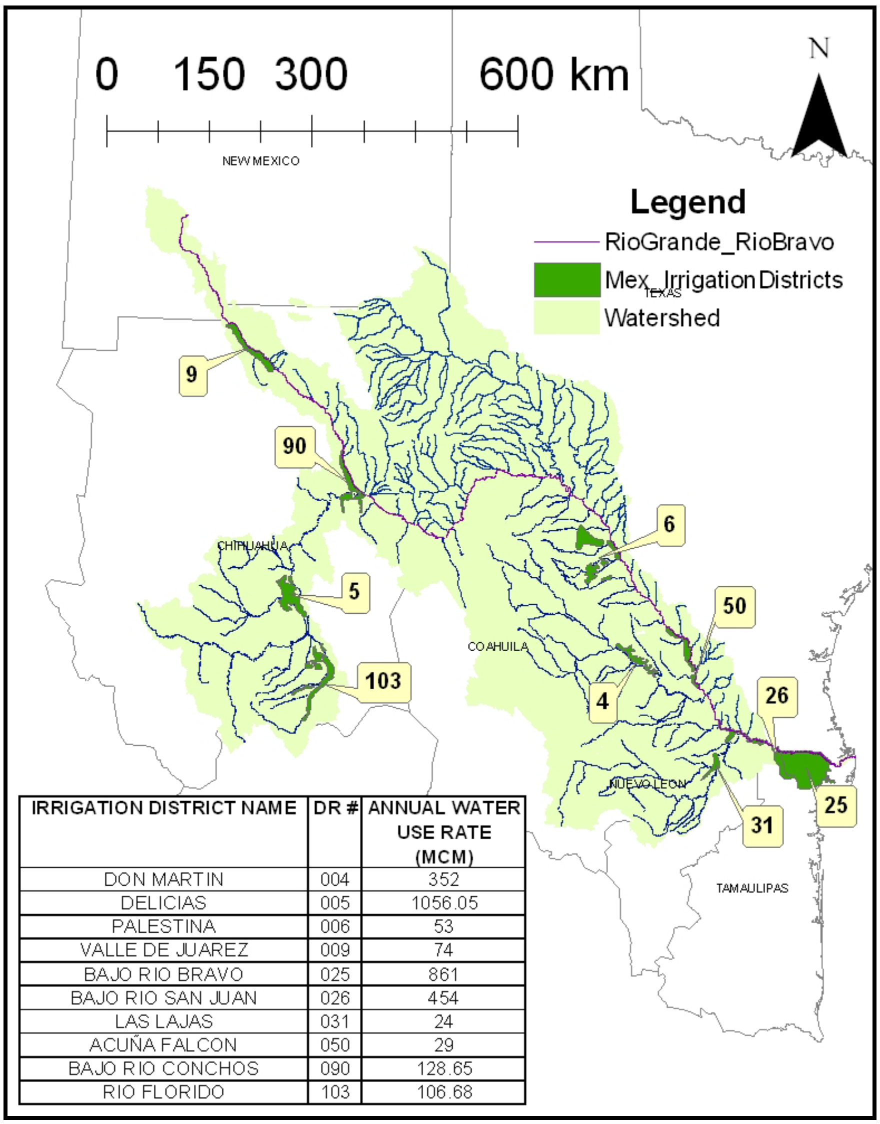
There are 11 Mexican municipalities represented in the model with a total annual water demand of 420.6 MCM. The eleven demand sites are listed below.

- Camargo
- Ciudad Acuna
- Ciudad Anhuac
- Ciudad Juarez
- Matamoros
- Metropolitan Monterrey
- Nuevo Laredo
- Reynosa
- Piedras Negras
- Ciudad Chihuahua
- Ciudad Miguel Aleman.

The priority level for all of these demand sites are entered using the following expression “Key\Priorities\Municipal” which relates back to the Key Assumptions generating a priority level of one.

II. Mexican Irrigation Demands

There are two types of irrigation demands for the Mexican region of the basin. The first is the large Irrigation Districts (DR) which are supplied by surface water. There are a total of 10 DRs in the model that require an annual water use rate of 3,031.7 MCM (Figure 10). The second type of irrigation is the smaller districts called Uderales (URs) where groundwater is the source of water supply. There are 25 URs in the model with an annual water use rate of 1,655.3 MCM (Appendix C, Table 15). The demand priorities for the DRs vary based on their location within the basin as shown in Appendix C, Table 14 and the priority level for the URs are all level one (Appendix C, Table 15).



IRRIGATION DISTRICT NAME	DR #	ANNUAL WATER USE RATE (MCM)
DON MARTIN	004	352
DELICIAS	005	1056.05
PALESTINA	006	53
VALLE DE JUAREZ	009	74
BAJO RIO BRAVO	025	861
BAJO RIO SAN JUAN	026	454
LAS LAJAS	031	24
ACUÑA FALCON	050	29
BAJO RIO CONCHOS	090	128.65
RIO FLORIDO	103	106.68

Figure 10: Mexican Irrigation Districts

III. US Demand Site Assumptions

Various assumptions have been made in order to accommodate the complicated structure of the US water demands. One assumption is the aggregation of water rights in Texas based on the Texas Watermaster river reaches as shown in Appendix D, Table 19, and the water rights for New Mexico are based on the IBWC Draft Environmental Impact Statement (DEIS) as shown in Appendix D, Figure 33: New Mexico Diversions Data (IBWC DEIS 2003a). There are over 2000 water rights holders for the Middle and Lower Subbasin in Texas and representing each of these has a separate demand in the model is impractical. The water rights include all use types: agriculture, municipalities, mining, industrial and other. The water rights data were obtained from the Texas Commission on Environmental Quality (TCEQ) Water Availability Model (WAM) current allocation version (TCEQ 2005a).

IV. US Municipalities

There are 14 US municipal demand sites in the model requiring 359.05 MCM of water annually. The US demand sites are classified into two groups. The first group consists of the major cities of Brownsville, Del Rio, Eagle Pass, Laredo, McAllen, Muni Maverick, and the city of Balmorhea. The second group consists of the smaller municipalities which have been aggregated into groups: Texas Watermaster sections 2 and 5 - 13 and Below the Rio Conchos, the data were obtained from the TCEQ WAM current allocation version (TCEQ 2005a). The US municipalities are set at priority level one (Appendix C, Table 16).

V. US Irrigation Demands

There are two key states that play a role in this region, New Mexico and Texas, with 32 irrigation demand sites in the model requiring 8,291 MCM of water annually. There are more then 32 demand sites requiring irrigation water, but many of these demands have been aggregated and entered into the model. There are three irrigation diversions in the model for New Mexico requiring 5,466.2 MCM of water annually. Texas has several different systems for allocating water to irrigation demands. The annual requirement for Texas irrigation is 2,824.8 MCM per year. The US irrigation demands are set at priority level one (Appendix C, Table 17).

The three New Mexico diversions located in the Upper Subbasin are NM Percha Diversion, NM Leasburg Diversion, and NM Messilla Diversion. The data for these diversions were obtained from IBWC DEIS for the River Management Alternatives for the Rio Grande Canalization Project (RGCP) (IBWC DEIS 2003a and 2003b).

The Pecos River agriculture demands are entered by the either the water irrigation district (WID) or the water permit holder. The Red Bluff WID requires 140.2 MCM per year for agriculture. The demands are

listed in the model as Red Bluff Power Control, Red Bluff Ward WID 2, Red Bluff Water Pecos WID 3, Red Bluff Water Power Loving, Red Bluff Water Reeves WID 2, Red Bluff WID 1, Red Bluff WID 2, and Red Bluff 3. The five remaining demand sites located along the Pecos River belong to the individual permit holders, however Comanche Creek Water Rights AG and Coyanosa Draw Water Rights AG are combined permit holders for the these two creeks. Whereas, the demand sites for Joe B Chandler et al. Estate, John Edwards Robbins, and Mattie Banner Bell are individual permit holders requiring 42.2 MCM per year (TCEQ 2005a).

There are three agriculture demands for Texas that are not part of the Pecos or the Texas Rio Grande Watermaster Program: Below Conchos Agriculture, Forgotten River Agriculture, and AG EPC WID No. 1, requiring 1,003.6 MCM annually. The AG EPC WID refers to the El Paso County irrigation district. The Forgotten River includes the portion south of El Paso prior to the confluence of the Rio Grande/Bravo and the Rio Conchos. The demand site for Below the Rio Conchos is the aggregated agriculture demand below the Rio Conchos and above Amistad Reservoir.

The Texas Rio Grande Watermaster Program (TCEQ 2005b) applies to the area of the Rio Grande/Bravo below Amistad Reservoir. This program allocates water on an account basis where the municipal accounts are authorized a water-right amount for the year and given the highest priority. The irrigation accounts however are not guaranteed and rely on balances forward (the water remaining in the account from the previous year). Every month the Texas Watermaster determines how much water is unallocated and if there is a surplus then the surplus water is allocated to the irrigation accounts. The Region M Regional Water Plan (TWDB 2006a) explains how the basin is divided into Watermaster sections according to the Texas Water Code (Subchapter G, Chapter 11). These sections were entered into the model as consecutive sections from 1 to 13 (Appendix D, Table 19) rather then split between Middle and Lower Rio Grande/Bravo with two sets of numbers by reach. The model has eight Watermaster agriculture demand sites requiring 1,576.1 MCM annually; however, this water is not guaranteed and will not be delivered unless there is enough water available in system. This operation scheme is not established in the model, but is determined by the Texas Watermaster on a monthly basis.

VI. US Other Demands

There are 32 other US demands that can not be grouped into the above categories. These include mining, industrial, groundwater and other withdrawals all requiring a total annual water use rate of 7.75 MCM. Many of these demands do not have a water use requirement entered into the model at this time, which will cause this demand requirement to increase once they are entered. The groundwater demands are entered for each Texas County with a maximum annual withdrawal amount. The priority levels for all of these sites are set to one, which is the same as municipal (Appendix C, Table 18).

Supply and Resources

The Supply and Resources branch of the WEAP data is broken into five sections: Linking Demands and Supply, River, Groundwater, Local Reservoirs, and Return Flows. The first branch, Linking Demands and Supply, has a branch for every demand site and there are three tabs for this field: Linking Rules, Losses, and Cost. Currently data is available for the linking rules which in turn have three sub-tabs: Supply Preference, Maximum Flow Volume, and Maximum Flow Percent of Demand. Figure 11 shows the linking rules for the Camargo demand site as an example of the tabs and sub-tabs within the branch of *Supply and Resources → Linking Demands and Supply.*

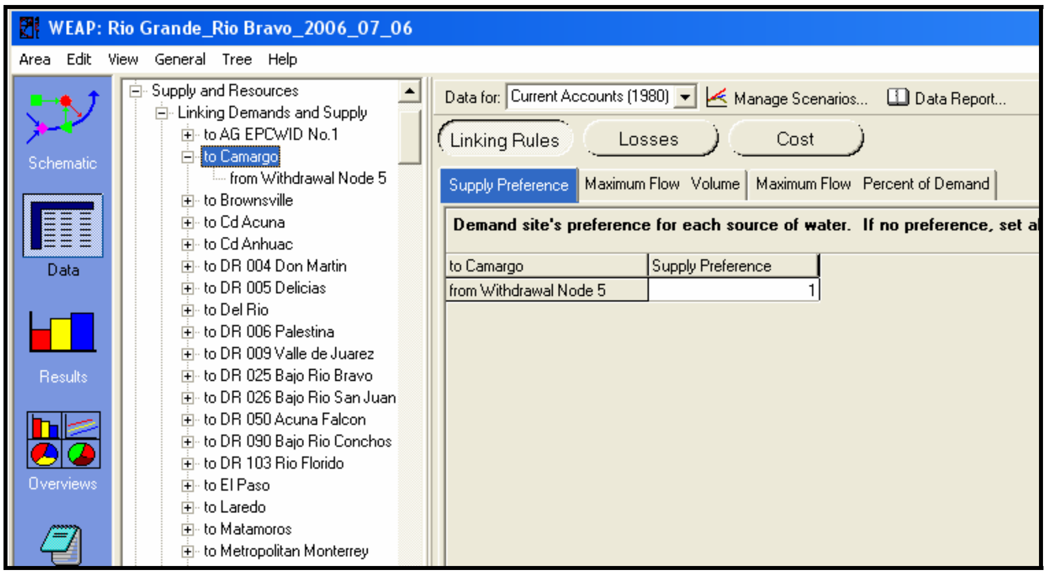


Figure 11: Camargo Example of Linking Rules

The second branch, River, has a branch for every tributary in the model and for all of the incremental flow sites which account for additional sources of the water for the basin. Each tributary has four branches: Reservoirs, Flow Requirements, Reaches and Streamflow Gauges. Figure 12 shows the four sub-tabs for the Rio Grande/Bravo branch located in *Supply and Resources → River → RioGrande_RioBravo.*

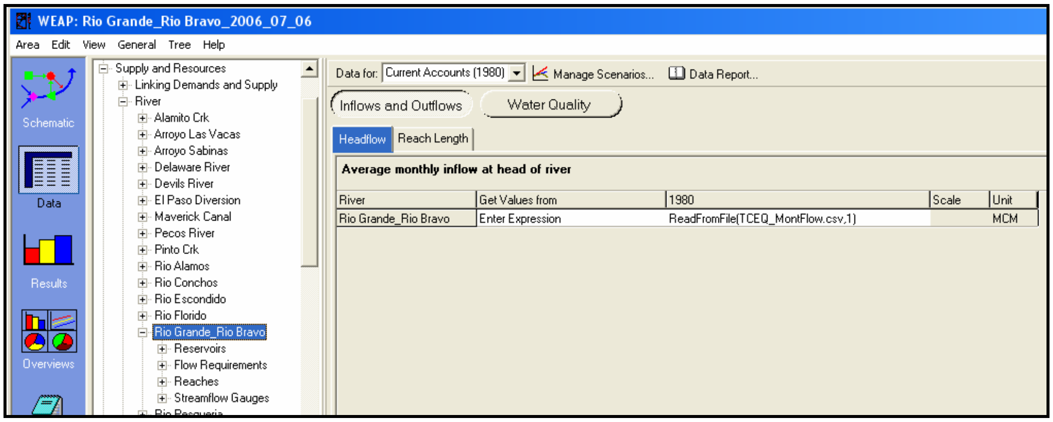


Figure 12: Rio Grande/Bravo River Example

The third branch, Groundwater, contains the data for the groundwater nodes in the model and is discussed in detail later in this section. The fourth branch, Local Reservoirs, contains the information for six small reservoirs in the system. The last branch, Return Flows, contains the data for any gains returning from the demand sites after consumption.

I. Reservoirs

The reservoir information that is entered into the model is located in two areas: Key Assumptions and Supply and Resources. Supply and Resources contains the reservoir characteristics. The fields currently being used are: Storage Capacity, Initial Storage, Volume Elevation Curve, Net Evaporation, Top of Conservation, Top of Buffer, Top of Inactive, Buffer Coefficient, and Priority. These are located under the Physical, Operation, and Priority tabs. The screen captures for each of these are shown in Figure 13, Figure 14, and Figure 15, respectively. Every reservoir in the system is assigned a priority level of 99, which is the lowest priority. The project is not currently looking at power generation or water quality; therefore, the fields for these are not in use. The reservoirs located under the river branch contain data; the current data that is available for each is shown in Appendix G, Table 28.

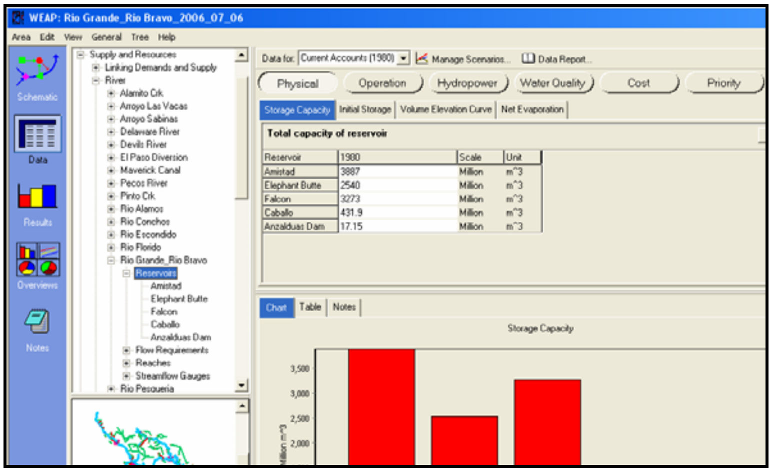


Figure 13: Example of the Physical Tab for Reservoirs

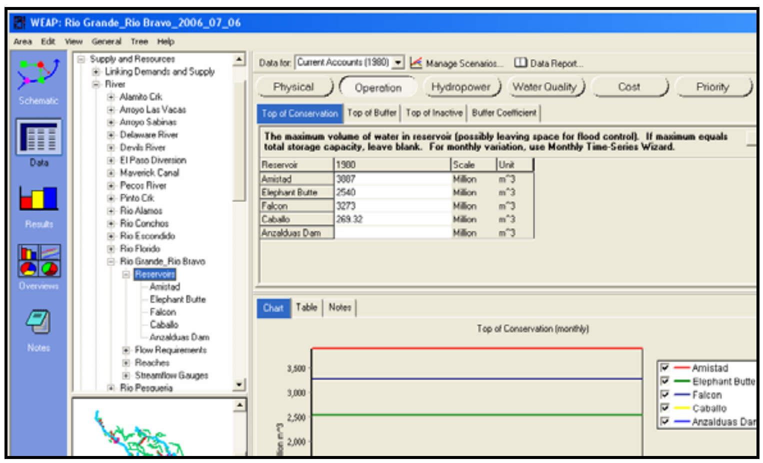


Figure 14: Example of the Operation Tab for Reservoirs

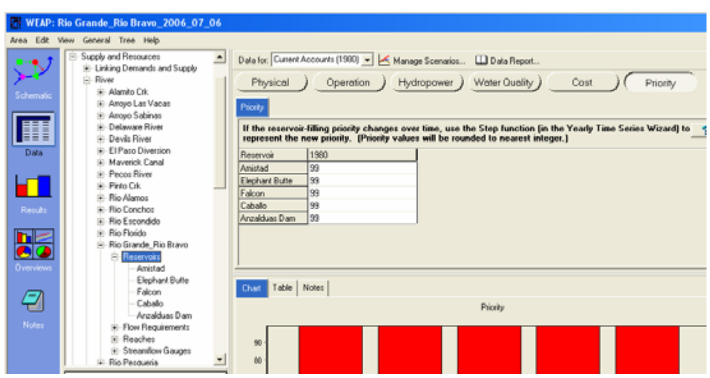


Figure 15: Example of the Priority Tab for Reservoirs

There are 23 reservoirs in the model, 17 of them are located in the River branch and the other six are located under Local Reservoirs. The total storage capacity for all 23 reservoirs is 22,034 MCM (Table 5)

and these reservoirs are owned and operated by the IBWC/CILA, US or Mexico. The two major international reservoirs are Amistad and Falcon as shown in Figure 16 and are owned and operated by IBWC/CILA with a total storage capacity of 7,177.2 MCM. Mexico owns and operates 14 reservoirs with a total storage capacity of 11,424.3 MCM (Figure 17) and the US owns and operates five reservoirs containing 3,432.7 MCM (Figure 18) of storage capacity. For each of the reservoirs, data are entered into the model for Storage Capacity, Top of Conservation and Top of Inactive as shown in Table 5. The Top of the Buffer is entered into the model as equal to the Top of Inactive for some reservoirs. The volume-elevation curves are referenced to the area-elevation-volume curves (Appendix F). Some of the curves have not been included in the model yet. Net evaporation data are entered as monthly values from the historical evaporation in comma delimited (.CSV) file.

Table 5: WEAP Inputs for Reservoir Characteristics

Owner	Reservoir	Storage Capacity (MCM)	Top of Conservation (MCM)	Top of Inactive (MCM)
IBWC/CILA[1]	Amistad	3887.0	3887.0	23.0
IBWC/CILA[1]	Anzalduas Dam	17.2	-	-
IBWC/CILA[1]	Falcon	3273.0	3273.0	100.0
Mexico[2]	Centenario	26.9	25.3	0.9
Mexico[2]	Cerro Prieto	392.0	300.0	24.8
Mexico[2]	Chihuahua	26.0	-	1.6
Mexico[2]	El Cuchillo	1784.0	1123.0	100.0
Mexico[2]	F. Madero	539.0	348.0	9.7
Mexico[2]	La Boca	42.6	39.5	0.8
Mexico[2]	La Boquilla	3336.0	2903.3	129.7
Mexico[2]	La Fragua	80.8	45.5	8.9
Mexico[2]	Las Blancas	134.0	90.5	12.5
Mexico[2]	Luis L. Leon	876.0	337.0	42.5
Mexico[2]	Marte R. Gomez	2303.9	994.7	23.4
Mexico[2]	Pico del Aguila	86.8	50.0	10.7
Mexico[2]	San Gabriel	389.6	255.4	34.0
Mexico[2]	San Miguel	21.7	20.2	0.5
Mexico[2]	V. Carranza	1385.0	1384.2	1.0
US[3]	Caballo	431.9	269.3	-
US[1]	Casa Blanca Lake	23.4	-	-
US[4]	Elephant Butte	2540.0	2540.0	254.0
US[1]	Lake Balmorhea	7.8	-	-
US[1]	Red Bluff	425.7	413.4	3.7
US[1]	San Esteban Lake	3.8	-	-
	Total	22034.1	18299.3	527.8

1. Source: TWDB 1971
2. Source: IMTA/CNA
3. Source: USBR 2006a
4. Source: USBR 2006b

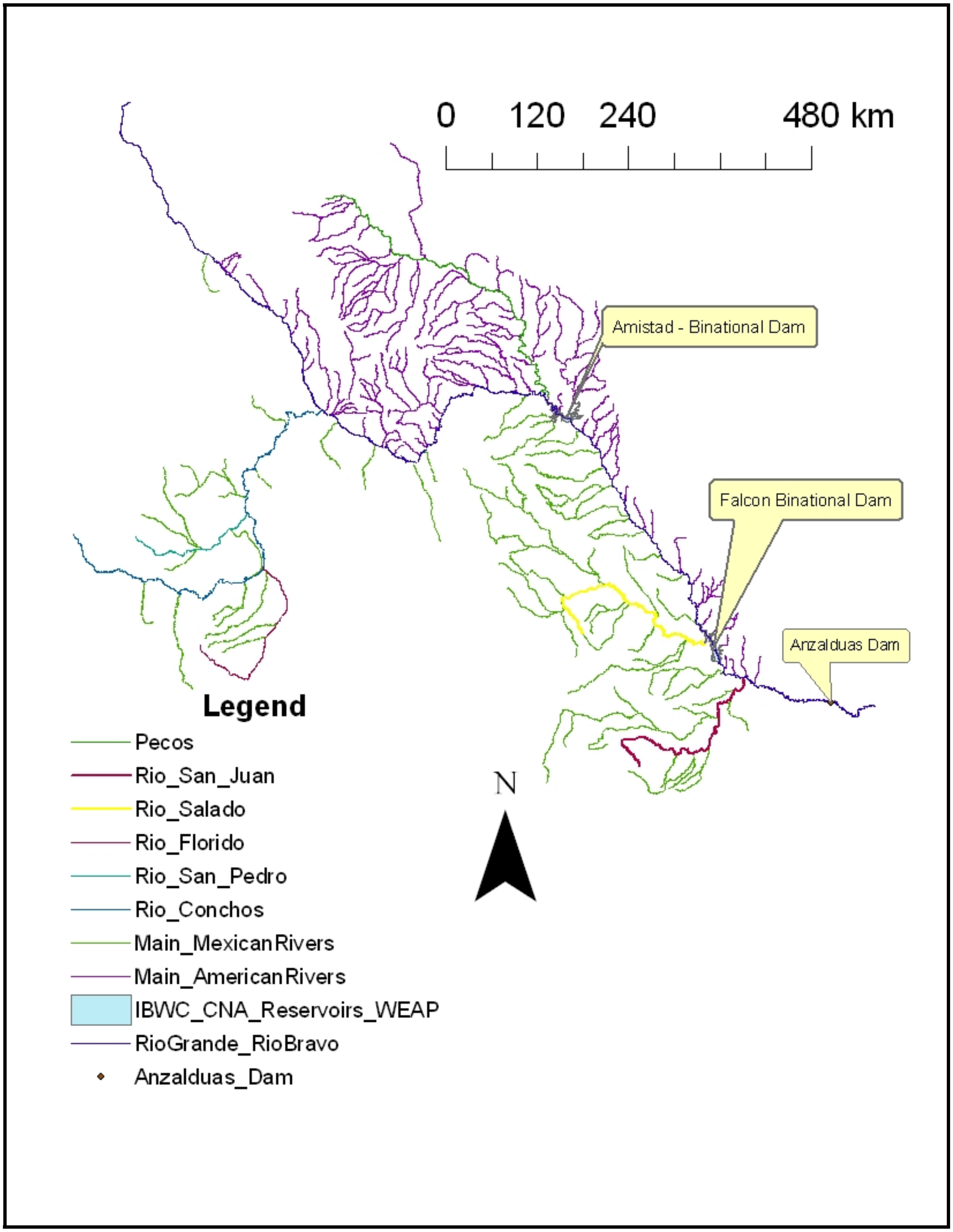


Figure 16: IBWC/CILA Reservoirs

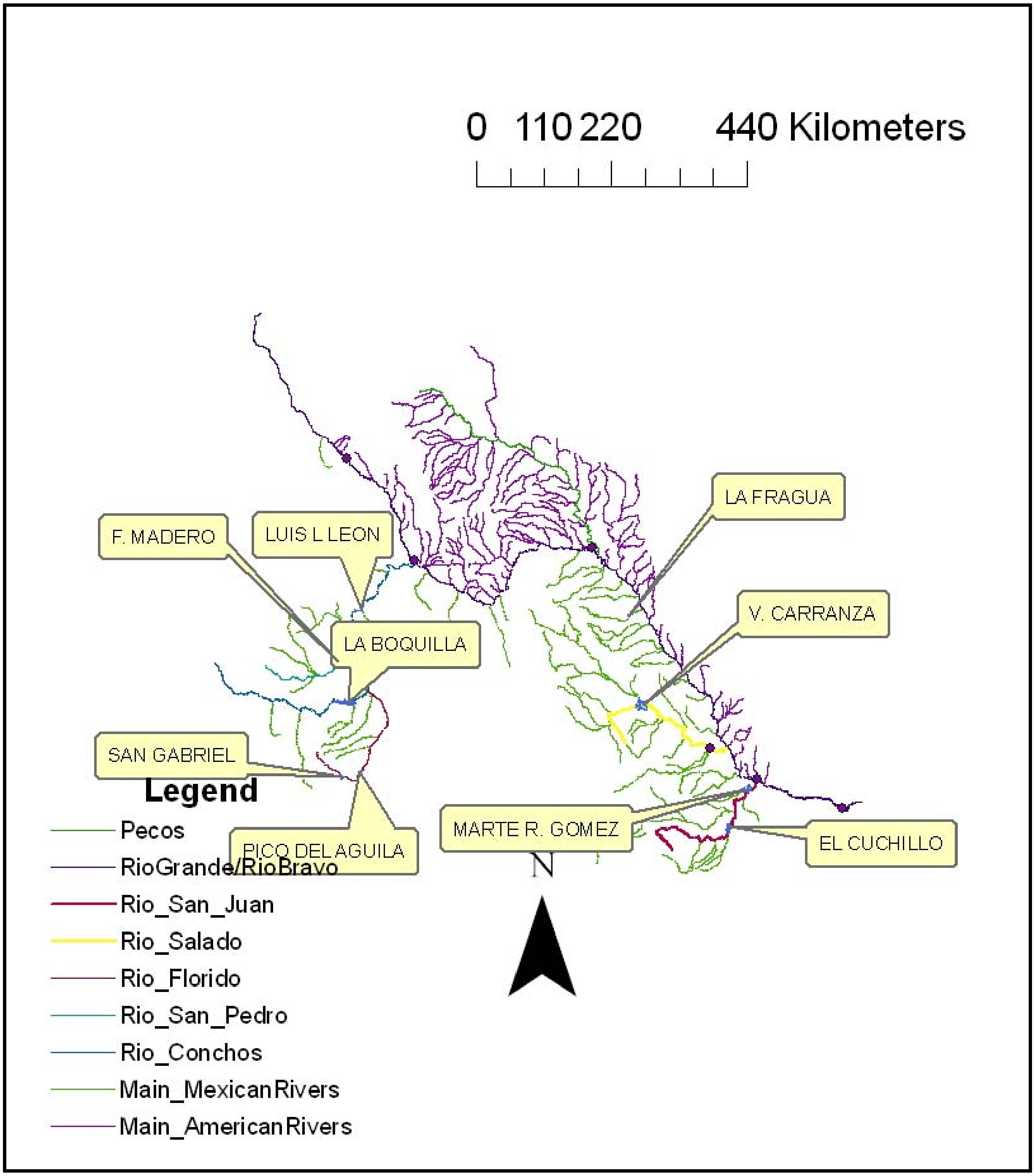


Figure 17: Mexican Reservoirs

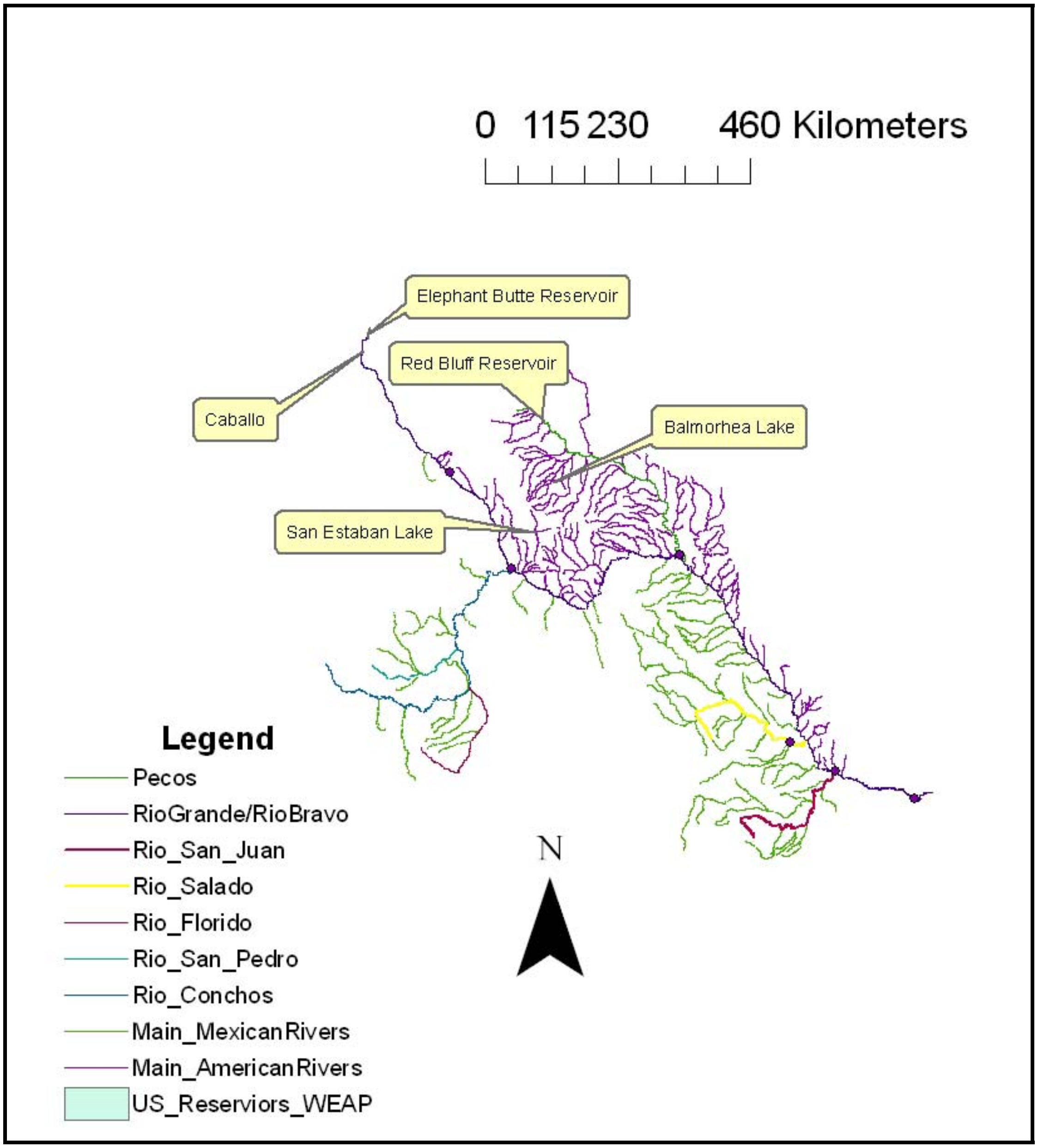


Figure 18: US Reservoirs

II. Flow Data

The model is driven by streamflow. Streamflow sources must be entered into the model as headflows. There are two are the types of headflows. The first type is the headflow for each river and creek, and the second is incremental flow. The first type, river/creek headflow was obtained from the naturalized flows for the TCEQ WAM for the Rio Grande (TCEQ 2005a, Brandes 2003). There are 21 rivers and creeks that have been entered into the model with their headflows (Figure 19); however the data for Toyah Creek is unavailable. The naturalized streamflow is the water that would flow in the river basin without any anthropogenic effects (Teasley and McKinney 2005). The naturalized streamflows were calculated using the following equation (Brandes 2003):

Naturalized Streamflow = Historical Gaged Streamflow
+ Historical Upstream Diversions
- Historical Upstream Return Flows
+ Historical Changes in Upstream Reservoir Storage
+ Historical Upstream Reservoir Evaporation Loss
- Historical Upstream Miscellaneous Adjustments

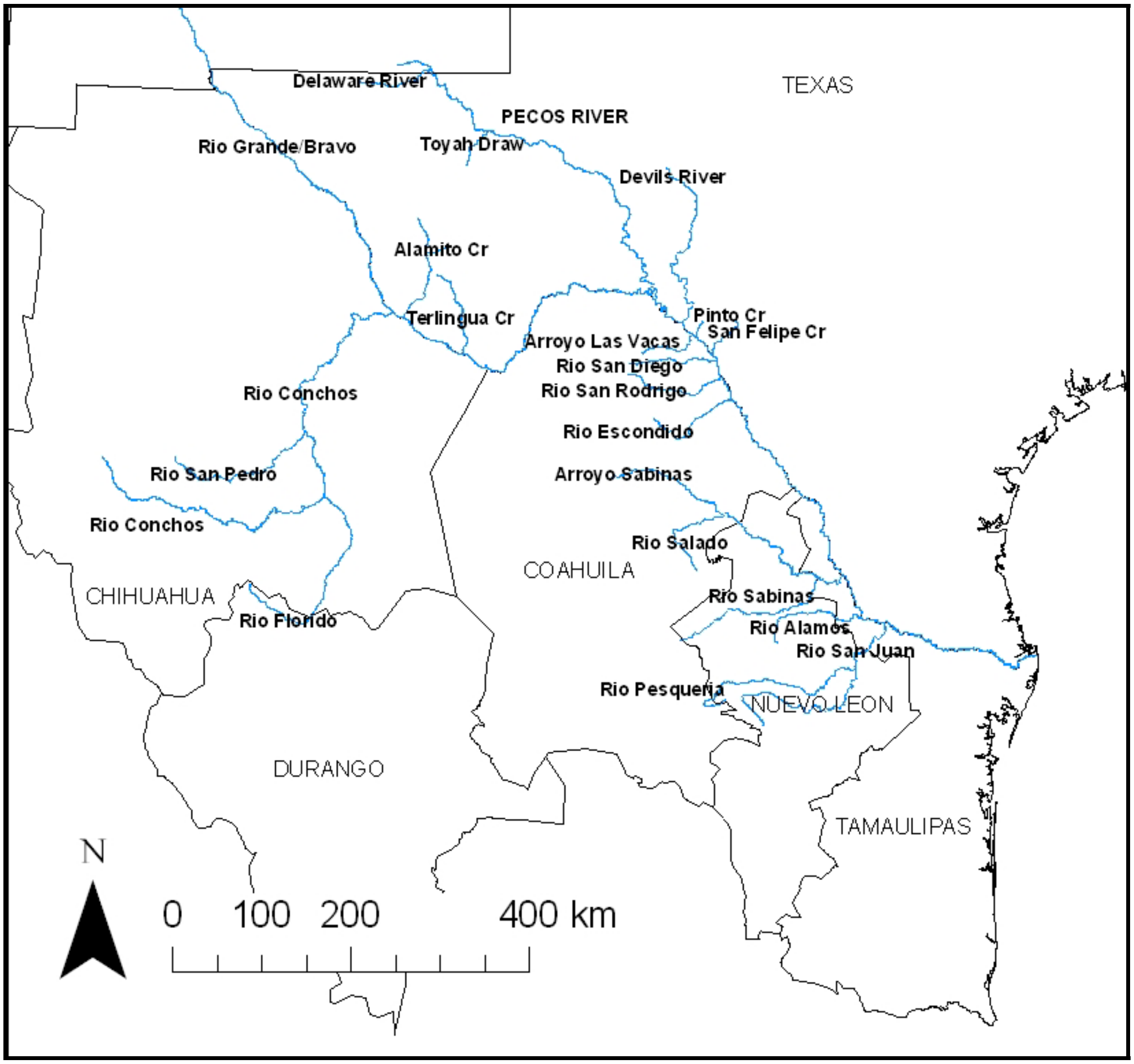


Figure 19: Rivers with TCEQ Naturalized Headflow for the WEAP Model

The second type of headflows are incremental flows. There are 22 incremental flows included in the model as shown in Figure 20. The incremental flows were calculated by taking the difference between the naturalized flows at the upstream gage and the naturalized flow at the downstream gage multiplied by the loss factor for that particular reach as follows:

*Incremental Flow = Downstream Naturalized Flow – Upstream Naturalized Flow * (1 – Loss Factor)*

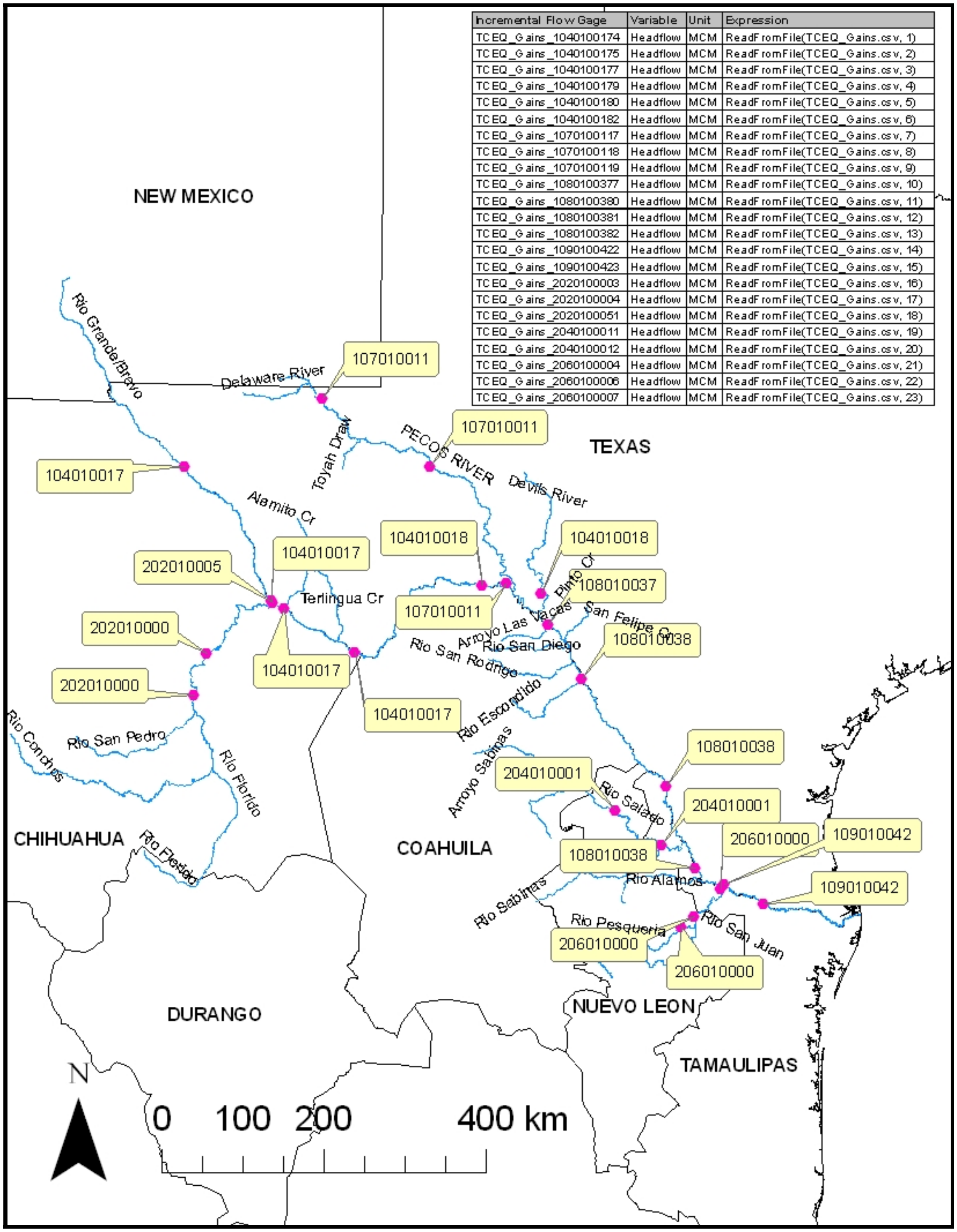
Eq. 1

Table 6: Loss Factors per Reach (Brandes 2003)

RJBCO REACH ID	RIVER	DESCRIPTION	REACH LENGTH River Miles	MEDIAN ANNUAL FLOW Ac-Ft/Yr	SEEPAGE LOSS RATE %	EVAP LOSS RATE %	SALT CEDAR LOSS RATE %	TOTAL LOSS RATE %	TOTAL LOSS RATE %/Mile
1	Rio Grande	El Paso to Ft. Quitman	83	19,978	9.1	7.3	3.1	20	0.24
2	Rio Grande	Ft. Quitman to Above Rio Conchos	209	138,442	23.3	4.3	18.3	46	0.22
3	Rio Grande	Below Rio Conchos to Johnson Ranch	88	686,004	9	0.5	0.3	10	0.11
4	Rio Grande	Johnson Ranch to Foster Ranch	205	737,378	Gaining	1.3	0.7	2	0.01
5	Rio Grande	Below Amistad Dam to Del Rio	13	1,813,100	Gaining	0.1	<< 1	0	0.01
6	Rio Grande	Del Rio to Quemado	31	1,811,128	6	0.2	<< 1	6	0.2
7	Rio Grande	Eagle Pass to Laredo	137	1,989,912	13	0.9	0.2	14	0.1
8 *	Rio Grande	Below Falcon Dam to Rio Grande City	40	2,506,053	7	*	*	7	0.18
9	Pecos River	Orla to Girvin	136	56,566	Gaining	4.4	44	48	0.35
10	Pecos River	Girvin to Langtry	160	20,362	Gaining	11	19	30	0.19
11	Devils River	Juno to Pafford Crossing	33	31,823	Gaining	1.3	3.1	4	0.14

*The streamflow gain/loss analysis for this reach utilized data for all months during the 1970-2000 period; therefore, the resulting streamflow loss rate includes the total effects of evaporation and plant uptake losses as they actually occurred on an annual basis.

If a negative value results in Equation 1, then the value is set to zero. The loss factors used in Equation 1 are shown in Table 6. The overall flow diagram for the model is shown in Appendix H.



Incremental Flow Gage	Variable	Unit	Expression
TCEQ_Gains_1040100174	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 1)
TCEQ_Gains_1040100175	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 2)
TCEQ_Gains_1040100177	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 3)
TCEQ_Gains_1040100179	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 4)
TCEQ_Gains_1040100180	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 5)
TCEQ_Gains_1040100182	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 6)
TCEQ_Gains_1070100117	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 7)
TCEQ_Gains_1070100118	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 8)
TCEQ_Gains_1070100119	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 9)
TCEQ_Gains_1080100377	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 10)
TCEQ_Gains_1080100380	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 11)
TCEQ_Gains_1080100381	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 12)
TCEQ_Gains_1080100382	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 13)
TCEQ_Gains_1090100422	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 14)
TCEQ_Gains_1090100423	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 15)
TCEQ_Gains_2020100003	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 16)
TCEQ_Gains_2020100004	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 17)
TCEQ_Gains_2020100051	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 18)
TCEQ_Gains_2040100011	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 19)
TCEQ_Gains_2040100012	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 20)
TCEQ_Gains_2060100004	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 21)
TCEQ_Gains_2060100006	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 22)
TCEQ_Gains_2060100007	Headflow	MCM	ReadFromFile(TCEQ_Gains.csv, 23)

Figure 20: Incremental Inflows from TCEQ Naturalized Flows

The last key factor considered for streamflow is to account for any losses that may occur along a reach. All of the losses have been grouped together as a percentage of flow in the reach and entered under *Supply and Resources → River → Reach → Evaporation*. This percentage accounts for: channel losses,

evaporative streamflow losses, evapotranspiration (plant uptake), and seepage (Teasley and McKinney 2005). Evaporation is entered for each reach between the two different types of headflow. The percentages for each reach are shown Figure 21 and the inputs into WEAP by reach are shown in Appendix I, Table 29.

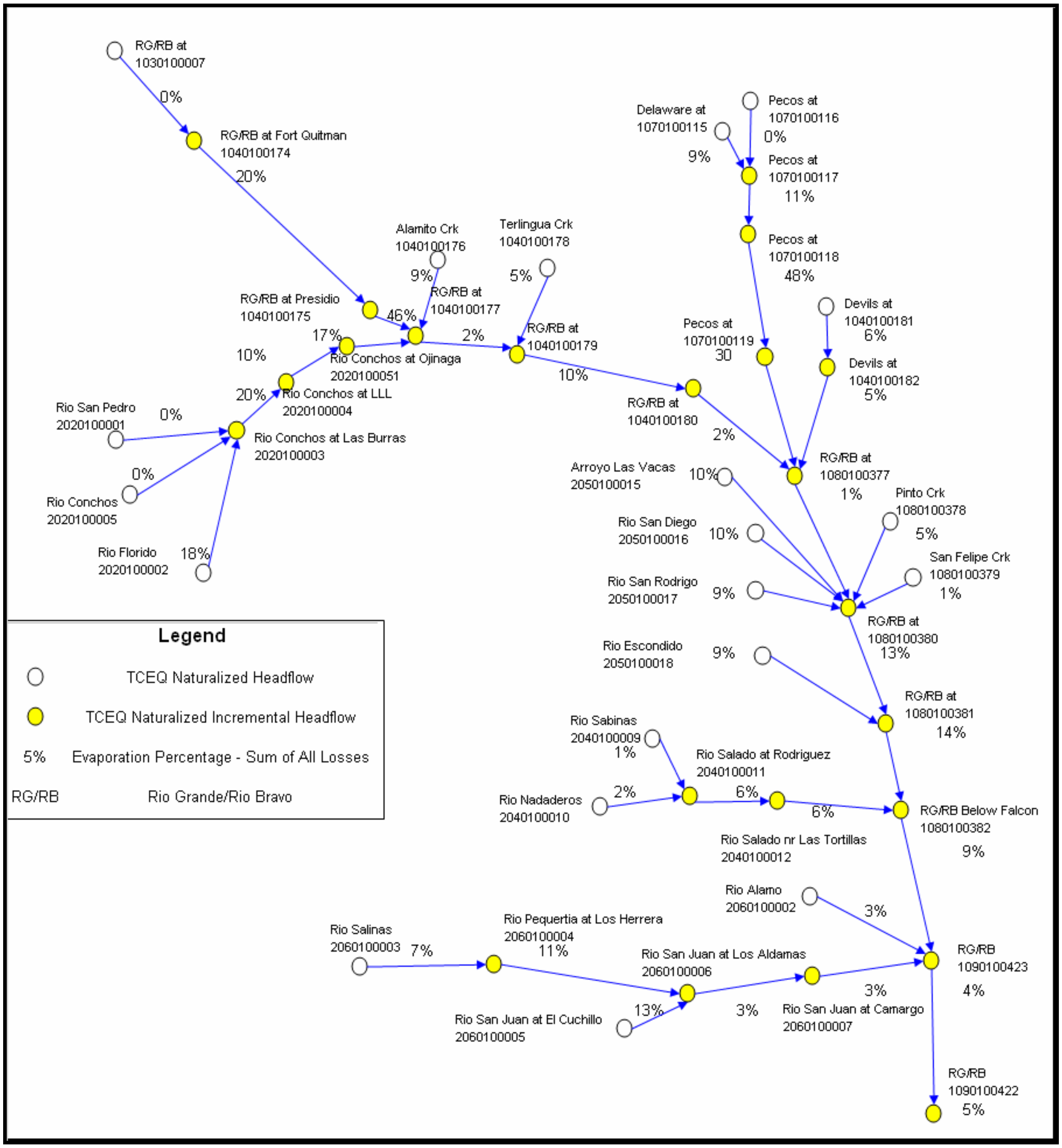


Figure 21: System Losses per Reach from TCEQ Naturalized Flows

III. Groundwater

Groundwater is a key source of water supply for the Rio Grande/Bravo Basin. WEAP has three tabs available for groundwater data inputs or expressions within the Supply and Resources branch: Physical, Water Quality, and Cost, as shown in Figure 22. Currently, data are only entered under the Physical tab which has four sub-tabs: Storage Capacity, Initial Storage, Maximum Withdrawal, Natural Recharge and Method. Initial Storage, Maximum Withdrawal, and Natural Recharge data for the Mexican aquifers was obtained from CNA (Villalobos et al. 2001). Initial storage is used as the maximum annual withdrawal volume. Monthly natural recharge is defined as the annual recharge volume divided by 12 to distribute it throughout the year. Maximum monthly withdrawal is defined as the initial storage volume plus the monthly natural recharge. The total maximum withdrawal is 3,285.6 MCM (Table 7) for all the Mexican aquifer nodes.

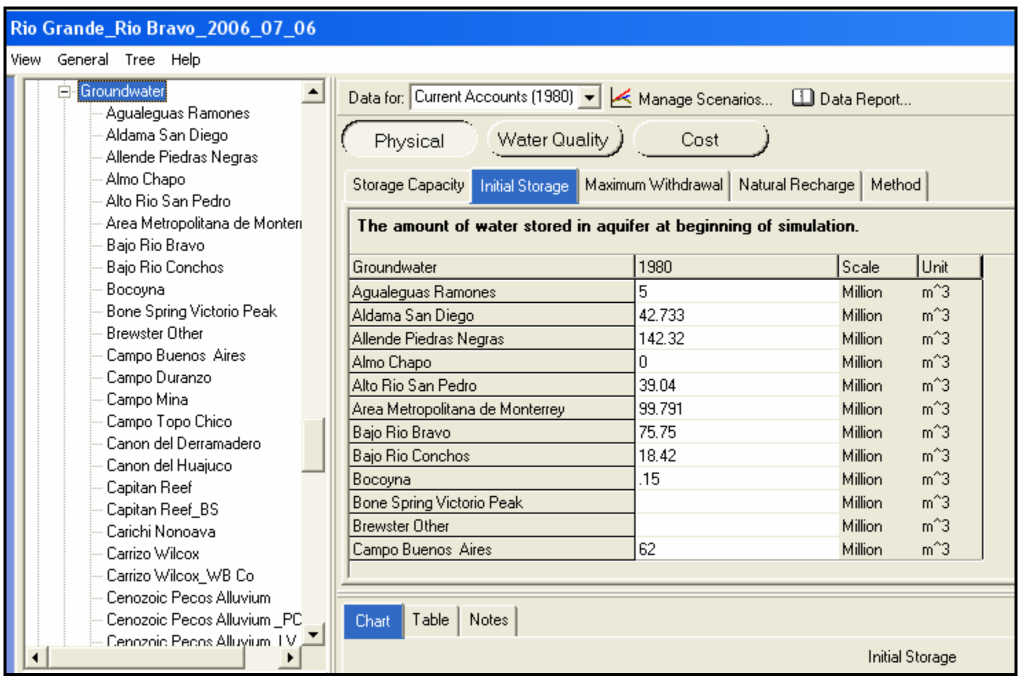


Figure 22: Groundwater Fields Available in WEAP

Table 7: Mexican Groundwater Node Characteristics (IMTA 2006)

Groundwater Node	Initial Storage (MCM)	Maximum Withdrawal (MCM)	Natural Recharge (MCM)
Agualeguas Ramones	5.0	6.0	1.0
Aldama San Diego	42.7	45.7	2.9
Allende Piedras Negras	142.3	153.2	10.8
Almo Chapo	0.0	1.0	1.0
Alto Rio San Pedro	39.0	43.7	4.7
Area Metropolitana de Monterrey	99.8	105.5	5.7
Bajo Rio Bravo	75.8	88.0	12.3
Bajo Rio Conchos	18.4	25.9	7.5
Bocoyna	0.2	1.6	1.4
Campo Buenos Aires	62.0	67.7	5.7
Campo Duranzo	5.0	5.4	0.4
Campo Mina	23.0	25.1	2.1
Campo Topo Chico	3.0	3.3	0.3
Canon del Derramadero	18.8	19.3	0.6
Canon del Huajuco	2.0	2.2	0.2
Carichi Nonoava	0.8	1.5	0.7
Cerro Colorado La Partida	6.2	7.0	0.8
Chihuahua Sacramento	124.8	129.4	4.6
China General Bravo	7.0	7.8	0.8
Citricola Norte	281.9	297.9	16.0
Cuatrocienegas	132.1	144.0	11.9
Cuatrocienegas Ocampo	34.9	39.4	4.4
Hidalgo	17.0	18.7	1.7
Jimenez Camargo	580.7	617.3	36.7
Laguna de Mexicanos	14.4	17.3	2.9
Lampazos Anahuac	63.0	68.4	5.4
Lampazos Villadama	13.0	14.5	1.5
Manuel Benavides	0.7	1.0	0.4
Meoqui Delicias	417.0	451.8	34.8
Monoclova	108.0	110.5	2.5
Paredon	23.0	24.6	1.6

Parral Valle Del Verano	22.9	25.2	2.2
Potrero del Llano	0.0	4.2	4.2
Region Carbonifera	177.2	190.6	13.4
Region Manzanera Zapaliname	48.3	52.9	4.6
Sabinas Paras	69.2	73.0	3.8
Saltillo Ramos Arizpe	50.7	53.2	2.5
San Felipe de Jesus	0.0	0.7	0.7
Santa Fe del Pino	4.0	4.9	0.9
Valle de Juarez	310.0	334.2	24.2
Valle de Zaragoza	0.5	1.6	1.1
Villalba	0.0	0.7	0.7

Model Testing

Model testing is the next step for evaluating the model confidence and the model data that have been discussed in the previous section. The model contains flow data from 1941 to the present; however, this is too long of a period to conduct testing since many conditions in the basin changed over this period; therefore, the time period of 1980 to 1999 was selected for testing. The WEAP model uses a water year starting in October; therefore, the exact time frame used in testing is October 1979 to September 2000. This time frame appeared most advantageous because there were minimal extreme events but still contained both a wet and dry period. Also, this is the time frame when all of the reservoirs of interest were in operation.

Comparison of Reservoir Storage Values

Eleven reservoirs were selected for testing as shown in Table 8 and Figure 23. The historical data for these reservoirs was taken from four major agencies, IMTA (BANDAS database), CNA, CILA, and USBR. The historical storage data was compared to the modeled reservoir storage values. Graphs of the historical reservoir storage per subbasin are shown in Appendix J.

Table 8: Reservoirs used for Testing

Subbasin	Name	HydroID	Reservoir Start Date	Agency Used for Historical Data
Lower	V. Carranza	2040400041	31-Jan-1930	IMTA/BANDAS
Lower	El Cuchillo	2060400104	31-Jan-1929	CNA
Lower	Falcon	2040400003	31-Jan-1968	CILA
Middle	Amistad	2030400002	31-Jan-1968	CILA
Pecos	Red Bluff	1070400633	31-Oct-1939	USBR
Rio Conchos	F. Madero	2020400058	31-Aug-1948	IMTA/BANDAS
Rio Conchos	La Boquilla	2020400095	31-Jan-1924	IMTA/BANDAS
Rio Conchos	Luis L. Leon	2020400030	29-Feb-1968	IMTA/BANDAS
Rio Conchos	San Gabriel	2020400081	31-Jan-1980	IMTA/BANDAS
Upper	Caballo	1030400017	28-Feb-1938	USBR
Upper	Elephant Butte	1020400390	31-Mar-1915	USBR

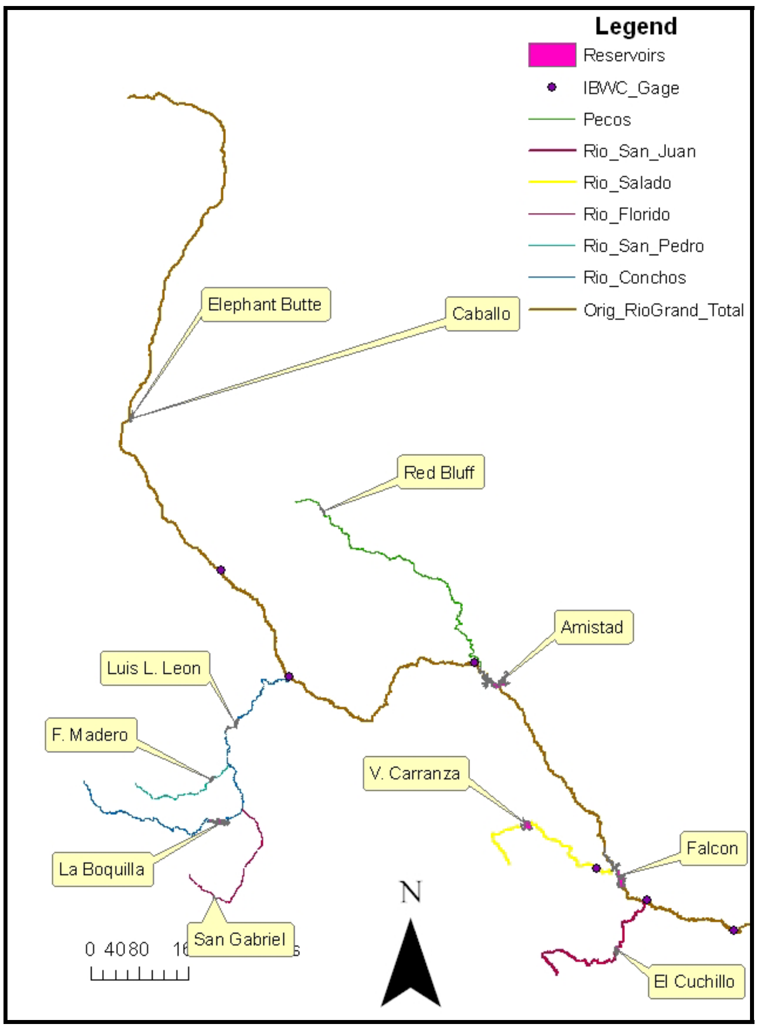


Figure 23: Eleven Reservoirs Used for Testing

First, the model was run with no changes to the inputs. These runs indicated that the initial storage values have a key influence on the results. Based on these results reservoir storage volumes were tested by running the model with four sets of initial storage values: full capacity, half capacity, the start of reservoir operations (start date), historical storage for each reservoir, and the storage value on September 1979 as shown in Table 9.

Table 9: Initial Storage Values used for Testing

Reservoir	HydroID	Initial Storage (MCM)				
		Full Capacity	Half Capacity	Start Date	Start Date Storage	Sep 1979 Storage
El Cuchillo	2060400104	1,784.00	892.00	31-Jan-29	1,118.00	1,052.00
Fancisco Madero	2020400058	539.00	269.50	31-Aug-48	5.42	348.90
La Boquilla	2020400095	3,336.00	1,668.00	31-Jan-24	2,635.00	2,334.00
Luis L. Leon	2020400030	876.00	438.00	29-Feb-68	18.56	352.50
San Gabriel	2020400081	389.60	194.80	21-Jan-80	67.70	70.00
V. Carranza	2040400041	1,385.00	692.50	31-Jan-30	5.61	1,280.00
Elephant Butte	1020400390	2,540.00	1,270.00	31-Mar-15	65.17	1,033.52
Caballo	1030400017	431.90	215.95	28-Feb-38	2.53	31.50
Amistad	2030400002	3,887.00	1,943.50	31-May-38	2.12	4,324.00
Falcon	2040400003	3,273.00	1,636.50	30-Jun-68	3,183.21	3,267.98
Red Bluff	1070400633	425.73	212.87	31-Oct-39	57.51	105.71

The Upper Subbasin was not used for additional analysis because the operation schemes for Elephant Butte and Caballo are still being developed and need to be adjusted. Currently, the operating rules for these reservoirs do not reflect real operations. Also, Red Bluff reservoir in the Pecos Subbasin was not used for analysis because the operating policy has not been obtained or entered into the model.

From these runs it was determined that the value of best initial storage was the value for each reservoir from September 1979. This was the monthly storage value of the month directly prior to the modeling period. The overall percent difference between the historical values and the modeled values for the 20-year time period for each reservoir is shown in Table 10. The graphs showing the comparison for each reservoir is found in Appendix K, Appendix L, and Appendix M. In general the reservoirs are allowing more water to be released than the historical data shows; however, this is not the case for Luis L. Leon and Red Bluff reservoirs.

Table 10: Percent Difference Over 20-year Period

Subbasin	Name	HydroID	Sum of Historical Monthly Storage (MCM)	Sum of Modeled Monthly Storage (MCM)	Reservoir % Difference over 20 year period
Lower	V. Carranza	2040400041	157,440	173,984	-11%
Lower	El Cuchillo	2060400104	167,353	215,769	-29%
Lower	Falcon	2040400003	458,822	651,903	-42%
Middle	Amistad	2030400002	780,089	774,197	1%
Rio Conchos	F. Madero	2020400058	50,084	56,756	-13%
Rio Conchos	La Boquilla	2020400095	402,145	457,009	-14%
Rio Conchos	Luis L. Leon	2020400030	99,051	67,103	32%
Rio Conchos	San Gabriel	2020400081	34,002	38,648	-14%

Evaluation of the operation schemes for the reservoirs showed that further investigation is needed into whether the Top of Inactive values need to be adjusted, or whether the operation scheme needs to be adjusted for the wet and dry periods in order to maintain additional storage in the reservoirs. Currently the reservoirs are releasing all of the water in storage to meet the demands. In addition, it was determined that some months are failing because there is no water in the system. These failure messages are shown in Appendix O.

A system for setting initial storage values needs to be developed so that there are two values used for each reservoir in the Key Assumptions. One method would be to set up a Key Assumption for wet and dry periods, so that the model would use one value for the wet period and the alternate value for the dry period. Another method would be to set up the Key Assumption linking to a CSV file containing the historical storage values and writing an expression in WEAP that would use the month prior to the modeled time period for the initial storage; this would eliminate the need for manually entering in the initial storage values for new modeled time periods while still maintaining valuable results.

Comparison of Gages Flows

Historical streamflow data from six IBWC gages were examined and compared to modeled streamflow values for the same locations (Table 11). The model does not reflect streamflow at the actual gauge; therefore the data is calculated as the streamflow below the node directly upstream of the gauge with no other inflows or major losses. The model reports total values of flow for each month, rather than average values. Therefore, the IBWC historical daily streamflow data was summed for each month and then compared to the modeled streamflow results.

For the purposes of this analysis, the gauge that will be discussed in detail is the Ojinaga/Presidio gauge which is located directly downstream of the confluence of the Rio Conchos. The historical streamflow was compared to the modeled streamflow in the reach below the Rio Conchos Inflow node as shown in Figure 25. The modeled streamflow is higher then the historical streamflow by 74 percent over the 20-year testing period (Table 12). The graphs of the historical and modeled streamflow are shown in Appendix N. Comparison of the streamflow data and the reservoir data show that the current representation of the operation of the reservoirs is releasing too much water and this causes the modeled streamflow values to be higher then the historical values. In addition, the channel losses might need to be adjusted to account for additional losses along the reach than just the estimated losses being used now. Note that no model calibration has been performed to modify these loss values. The percent difference between the historical and the modeled streamflow for each IBWC gage is shown in Table 12 for the 20-year period.

Table 11: IBWC Gages Compared to Model Reaches

River	IBWC Gage Name	IBWC Gage Number	Closest Upstream Node
Rio Grande/Bravo	Ft Quitman	1040700004	TCEQ_1040100174
Rio Grande/Bravo	Ojinaga/Presidio	1040700009	Rio Conchos Inflow
Pecos River	Pecos	1070700001	TCEQ_1070100119
Rio Salado	Rio Salado	1080700029	TCEQ_2040100012
Rio Grande/Bravo	Rio Grande City	1090700003	TCEQ_1090100423
Rio Grande/Bravo	Brownsville	1090700007	Return Flow Node 24

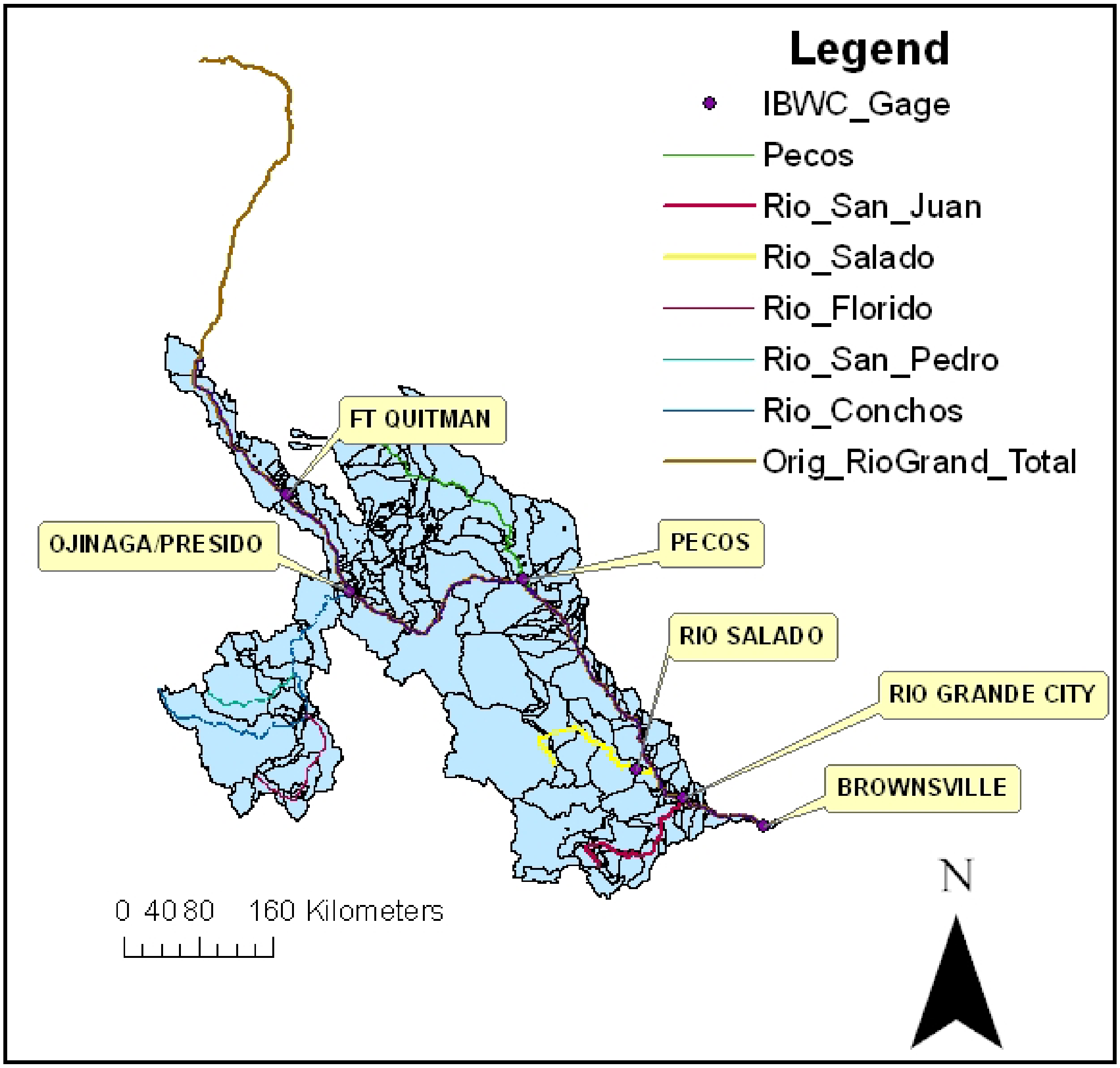


Figure 24: Six IBWC Gages Used for Testing

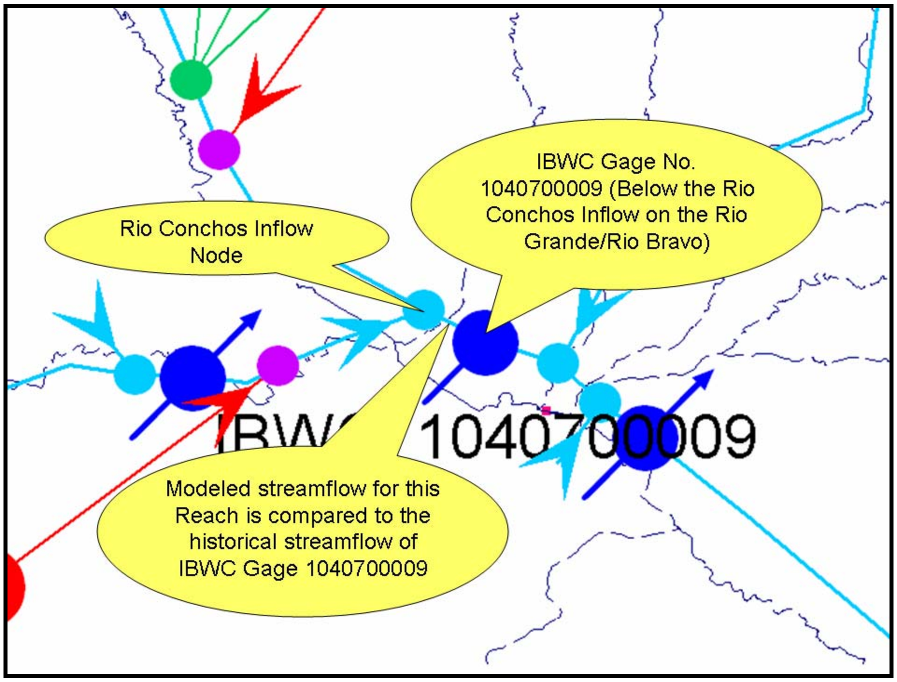


Figure 25: WEAP Screen Capture for Streamflow Comparison

Table 12: Percent Difference for 20-year Period

River	IBWC Gage Name	IBWC Gage Number	Sum of Historical Monthly Streamflow (MCM)	Sum of Modeled Monthly Streamflow (MCM)	% Difference over 20-year Period
Rio Grande/Rio Bravo	Ft Quitman	1040700004	66,181	46,120	30%
Rio Grande/Rio Bravo	Ojinaga/Presidio	1040700009	266,047	69,582	74%
Pecos River	Pecos	1070700001	47,642	13,696	71%
Rio Salado	Rio Salado	1080700029	46,721	35,919	23%
Rio Grande/Rio Bravo	Rio Grande City	1090700003	688,720	335,284	51%
Rio Grande/Rio Bravo	Brownsville	1090700007	110,649	35,079	68%

Model Errors

When the model is run there are several error messages that are generated. These messages can be grouped into two types: warning and failure. The warning errors are shown in Figure 26 and repeat themselves for multiple model runs. These messages mostly apply to the current accounts scenario. The failure messages appear to be generated whenever there is insufficient water in the system to meet all the demands. All of the failure messages for the model for the run on July 13, 2006 are shown in Appendix O.

Year	Month	Branch	Message
1979	October		Failure to solve in month 10, year 1979. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 2, total iterations for this month 5')
1980		Demand Sites\Metropolitan Monterrey	WARNING: Return flow link "Return Flow from Metropolitan Monterrey to Rio Pesqueria" has data for routing share, and yet all the inflow to "Metropolitan Monterrey" is consumed. You probably need to enter the consumption fraction. Double-click this message to go to this variable in the Data View.
1980		Demand Sites\DR 025 Bajo Rio Bravo	WARNING: Not all the inflow to "DR 025 Bajo Rio Bravo" is consumed but there are not any return flow links to carry away the wastewater. You probably need to create return flow links. Double-click this message to go to this variable in the Data View.
1980		Demand Sites\DR 026 Bajo Rio San Juan	WARNING: Return flow link "Return Flow from DR 026 Bajo Rio San Juan to Rio Grande_Rio Bravo" has data for routing share, and yet all the inflow to "DR 026 Bajo Rio San Juan" is consumed. You probably need to enter the consumption fraction. Double-click this message to go to this variable in the Data View.
1980		Demand Sites\DR 004 Don Martin	WARNING: Return flow link "Return Flow from DR 004 Don Martin to Rio Salado" has data for routing share, and yet all the inflow to "DR 004 Don Martin" is consumed. You probably need to enter the consumption fraction. Double-click this message to go to this variable in the Data View.
1980		Demand Sites\DR 050 Acuna Falcon	WARNING: Return flow link "Return Flow from DR 050 Acuna Falcon to Rio Grande_Rio Bravo" has data for routing share, and yet all the inflow to "DR 050 Acuna Falcon" is consumed. You probably need to enter the consumption fraction. Double-click this message to go to this variable in the Data View.
1980		Demand Sites\DR 006 Palestina	WARNING: Return flow link "Return Flow from DR 006 Palestina to Rio Grande_Rio Bravo" has data for routing share, and yet all the inflow to "DR 006 Palestina" is consumed. You probably need to enter the consumption fraction. Double-click this message to go to this variable in the Data View.
1980		Demand Sites\DR 009 Valle de Juarez	WARNING: Return flow link "Return Flow from DR 009 Valle de Juarez to Rio Grande_Rio Bravo" has data for routing share, and yet all the inflow to "DR 009 Valle de Juarez" is consumed. You probably need to enter the consumption fraction. Double-click this message to go to this variable in the Data View.
1980		Demand Sites\AG EPCWID No.1	WARNING: Return flow link "Return Flow from AG EPCWID No.1 to Rio Grande_Rio Bravo" has data for routing share, and yet all the inflow to "AG EPCWID No.1" is consumed. You probably need to enter the consumption fraction. Double-click this message to go to this variable in the Data View.
1980		Demand Sites\Cd. Chihuahua	WARNING: Demand Site Cd. Chihuahua has no Transmission Links into it. Therefore, it will never have any inflow.

Figure 26: Warning Messages for WEAP Model Results as of July 13, 2006

Conclusion

This report falls under with the Physical Assessment Project, Task 3, "Constructing a Basin-Wide Model," by documenting the current data inputs and evaluating two key parameters, reservoirs, and IBWC streamflow gages for the WEAP model of the Rio Grande/Bravo river system. The basin-wide model was constructed using WEAP software for the Rio Grande/Bravo basin to be used by the two riparian nations, the United States (US) and Mexico. The model incorporates both natural and man-made impacts on the basin system.

The model has three main screen views: Schematic, Data, and Results. This report looks at the Data screen view in detail, including the three main branches: Key Assumptions, Demand Sites and Supply and Resources. There are 136 demand sites in the model, representing withdrawals for municipalities, irrigation, and other, with a total annual water requirement of 13,872 MCM. These demand sites are constrained by the Key Assumptions and the Supply and Resources that have been entered into the model. The main sources of water for these demand sites are located under *Supply and Resources → River* representing the reservoirs and headflows for each tributary. The data for the other source of water, groundwater, is located under *Supply and Resources → Groundwater* which provides additional water for this semi-arid region. The data entered for all of these fields have been provided from multiple sources and some data still need to be entered for the model to be complete; however, the current model demonstrates the current strain on the system and the need to manage these resources for optimal conservation.

The model testing phase reported here for the reservoirs and the IBWC gages demonstrates that for the period of 1980 to 1999 overall the model has more water in the system then shown in the historical records. Testing showed that the model results are sensitive to the initial reservoir storage values and show modeled storage values higher than historical values. The main reason for this difference is that the modeled reservoir operation policies do not directly reflect the actual actions of the operators. Also, the reservoirs are not maintaining any storage for the dry periods but instead are releasing storage in order to meet all the demands on the system. The streamflow gages also show that there is too much water in the modeled system. By looking at both the reservoirs and the streamflow the high and low peaks are in the same years as the historical values, therefore the headflows and climate changes are being represented in the model. The main difference between the historical and the modeled streamflow is the volume being released by the reservoirs. The reservoir where model results match the historical values the best is Amsitad, with only a one percent difference over the 20-year period.

Through testing and documentation it was found that the model is sensitive to the initial storage volumes for the reservoirs, loss factors for the reaches, headflows, and the demands. The demands are being met

based on priority levels. The model fails for particular months when all of the demands can not be met. This normally occurs in the dry periods where the model only meets the demands with a priority level of one.

The model contains some missing data that needs to be entered:

- *Key Assumptions → Falcon_Accounts → Outflows → Diversion_US* has no expression.
- Reservoir characteristics that have not been entered are shown in Appendix G.
- The reservoir operating policies for Elephant Butte and Caballo need to be added.

Recommendations for revising the priority levels for the demand sites would be to add a priority level for US irrigation. This would separate US municipal and irrigation into two categories. In addition, it would be a good idea to review all of the current demand priorities and adjust them to meet a set scheme. One method for laying out the priorities is shown in.

Table 13: Recommended Priority Level Structure

Demand Type	Priority Level
US and Mexican Municipal	1
US Irrigation	2
Mexican Uderales	3
Mexican Irrigation - For areas in the upper watershed	4
Mexican Irrigation - For areas in the middle watershed	5
Mexican Irrigation - For areas in the lower watershed	6
Treaty	7
Reservoir Storage	99

Another recommendation is to review the model in comparison to the geodatabase (Patiño-Gomez and McKinney 2005) to ensure synergy. An example would be to compare the geodatabase data for Mexican Irrigation Units and the WEAP data for Mexican Uderales to confirm if these are the same data set or two separate data sets.

Acknowledgements

I would like to thank Dr. Daene McKinney, Rebecca Teasley, and Dr. Carlos Patiño-Gomez for all of their help and support on this project. This project taught me that when you are working with two countries and one river things can get really sticky. The sensitivity to political issues and the various stakeholders has to be the number one priority. In addition, it is very difficult to work with a large basin, such as the Rio Grande/Bravo as a whole. The data is not always available at your finger tips and never in the format that works prior to data processing. I hope that I have been of assistance to this project team through my efforts of documenting the contents of this model.

Thank you and good luck!

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Appendix A. List of Acronyms

AG	Agriculture
CILA	Comisión Nacional de Límites y Aguas
CNA	Comisión Nacional de Agua
CRWR	Center for Research in Water Resources
CSV	Comma Separated Variables
DLL	Dynamic Linked Library
DR	Districto del Irrigation
GIS	Geographic Information Systems
GW	Groundwater
IBWC	International Boundary & Water Commission
IMTA	Instituto Mexicano de Tecnologia del Agua
MCM	Million Cubic Meters
NHI	National Heritage Institute
RJBCO	R.J. Brandes Company
SEI	Stockholm Environment Institute
TCEQ	Texas Commission on Environmental Quality
TWDB	Texas Water Development Board
UR's	Uderales (Mexican irrigation districts that are supplied by groundwater.)
USACE	U.S. Army Corp of Engineers
USBR	US Bureau of Reclamination
WAM	Water Availability Modeling
WEAP	Water Evaluation and Planning System
WID	Water Irrigation District
WRAP	Water Rights Analysis Package
WWF	World Wildlife Fund

Appendix B. Rio Grande/Bravo Subbasin Maps

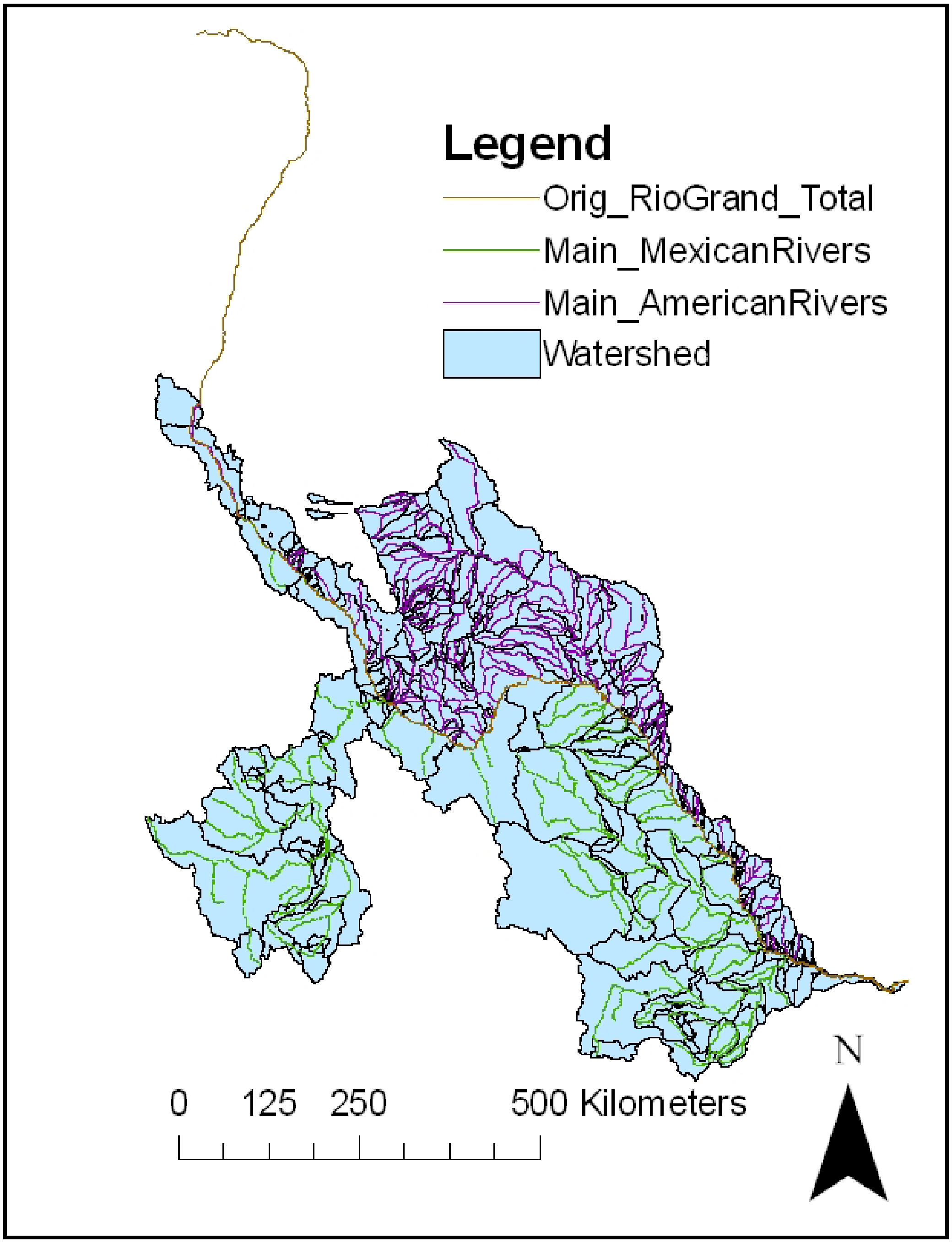

Figure 27: GIS Map of the Rio Grande/Bravo Basin

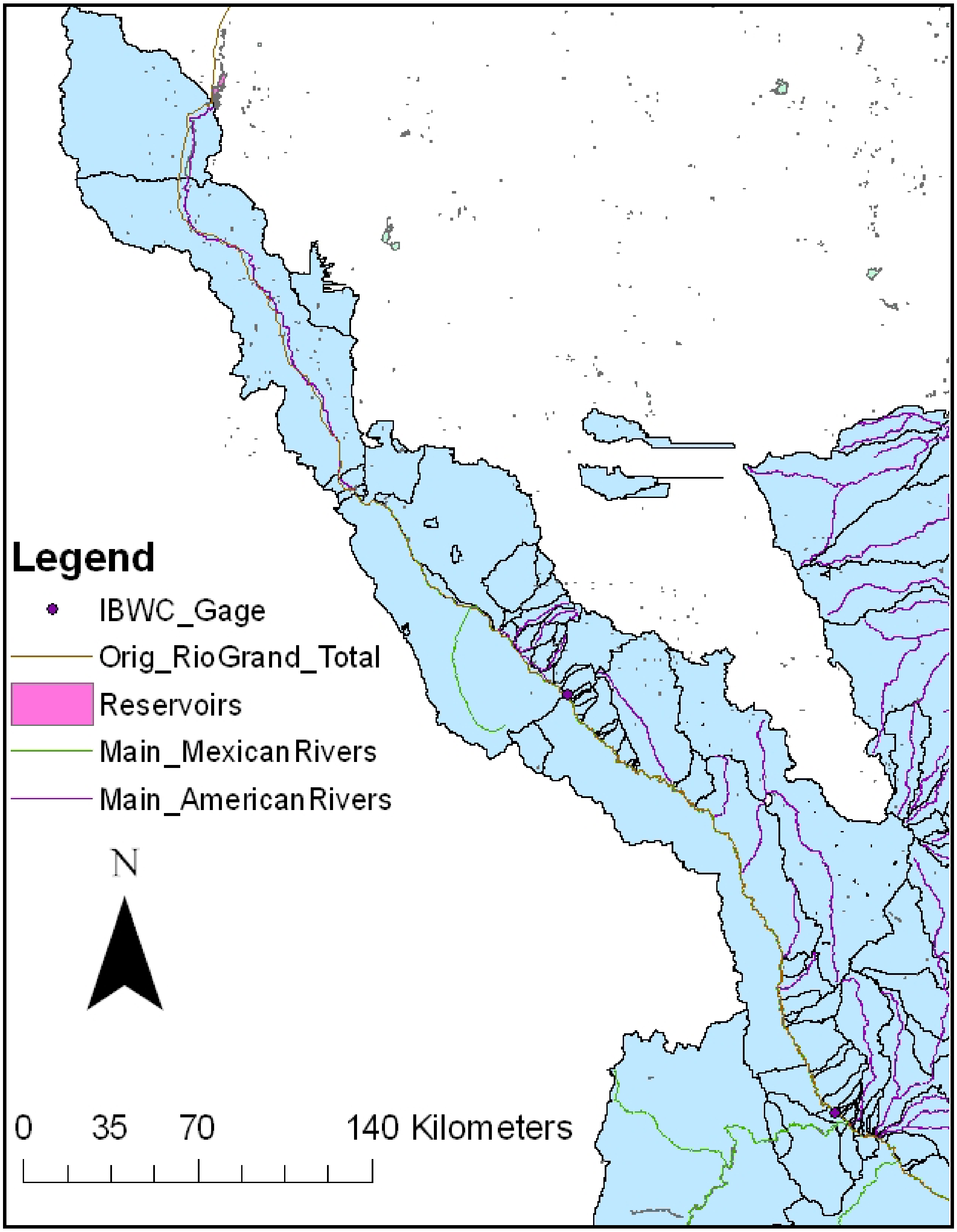

Figure 28: GIS Map of the Upper Rio Grande/Bravo Subbasin

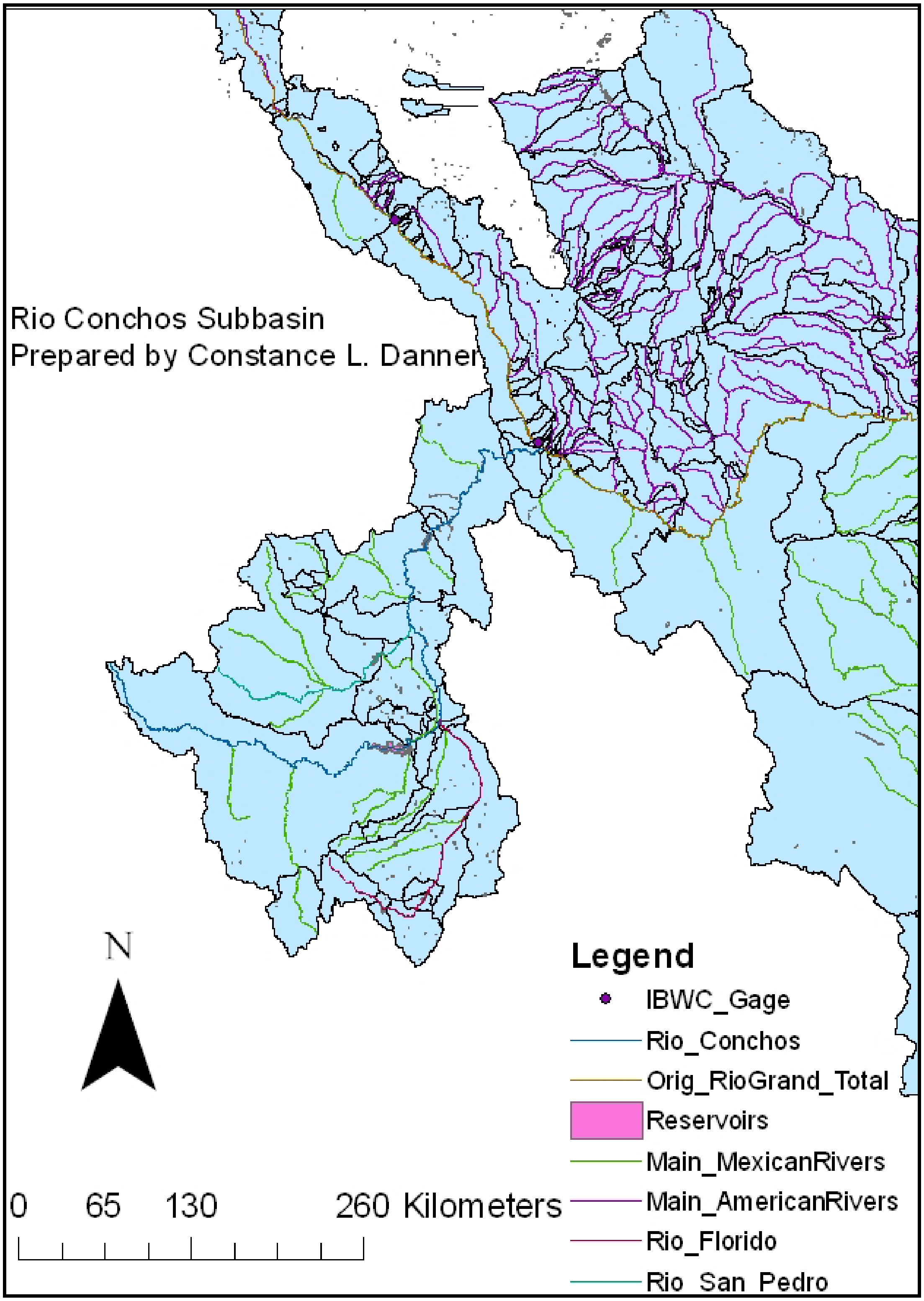

Figure 29: GIS Map of the Rio Conchos Subbasin

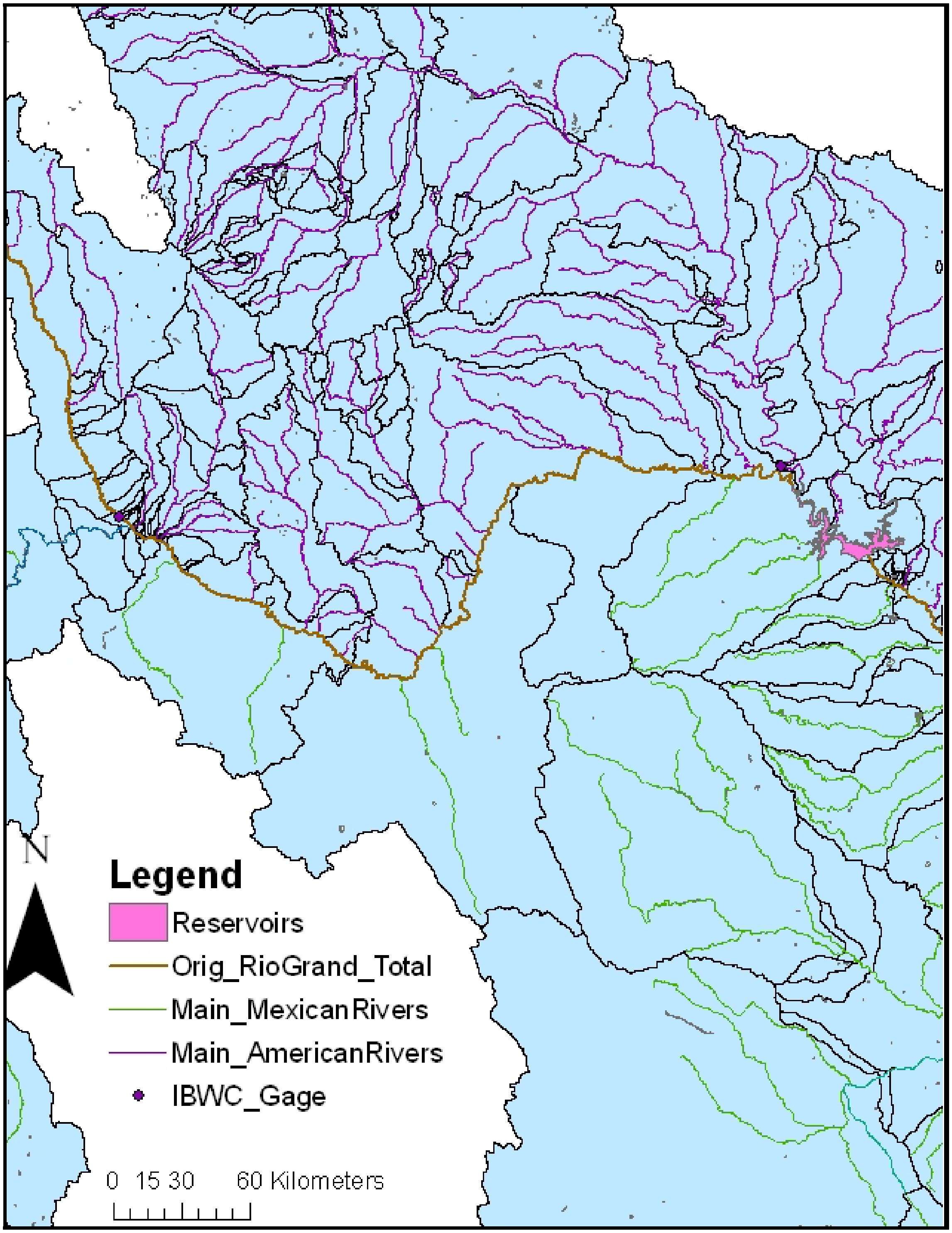

Figure 30: GIS Map of the Middle Rio Grande/Bravo Subbasin

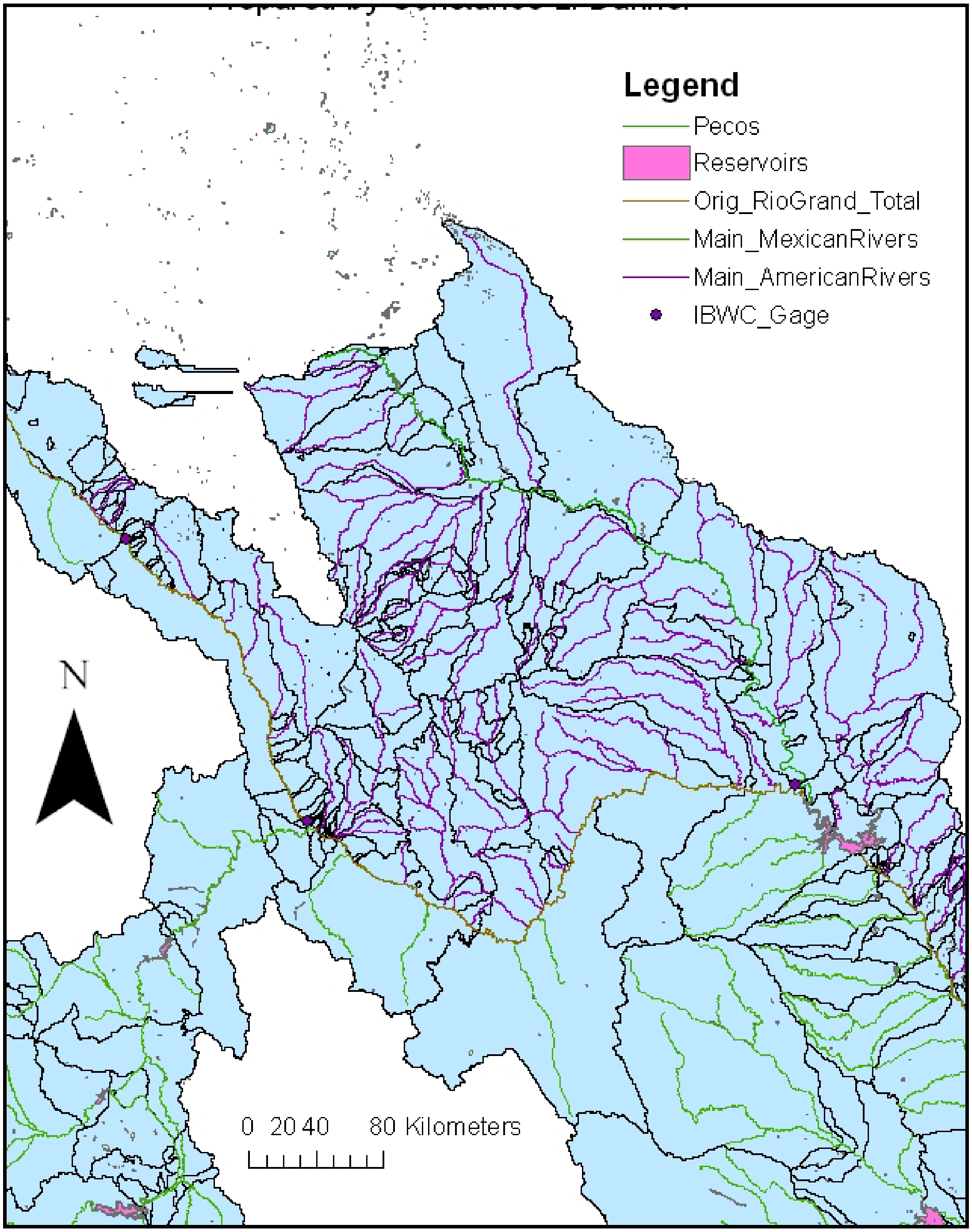

Figure 31: GIS Map of the Pecos River Subbasin

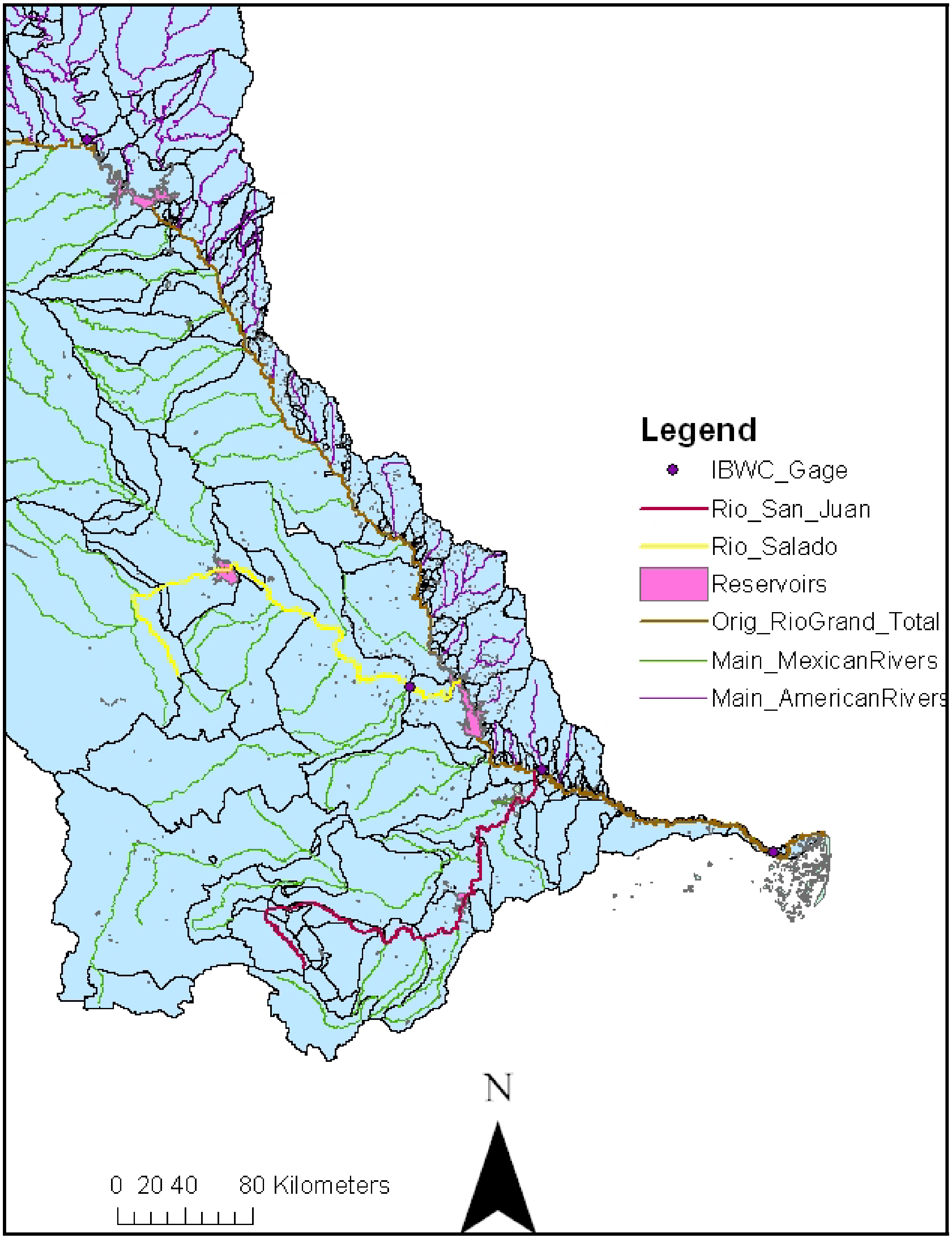

Figure 32: GIS Map of the Lower Rio Grande/Bravo Subbasin

Appendix C. Priority Levels for Demand Sites in WEAP Model

Table 14: Demand Priority Levels for Mexican Irrigation Districts

Demand Site	Expression or Demand Priority Level
DR 004 Don Martin	Key\Priorities\Irrigation1
DR 005 Delicias	Key\Priorities\Irrigation1
DR 006 Palestina	Key\Priorities\Irrigation3
DR 009 Valle de Juarez	Key\Priorities\Irrigation1
DR 025 Bajo Rio Bravo	Key\Priorities\Irrigation3
DR 026 Bajo Rio San Juan	4
DR 031 Las Lajas	Key\Priorities\Irrigation1
DR 050 Acuna Falcon	Key\Priorities\Irrigation3
DR 090 Bajo Rio Conchos	Key\Priorities\Irrigation2
DR 103 Rio Florido	Key\Priorities\Irrigation1

Table 15: Uderales in WEAP Model (Villalobos 2001)

UR's in WEAP	Annual Water Use Rate (MCM)	Expression or Demand Priority Level
URs Agualeguas Ramones	2.0	1
URs Aldama San Diego	20.7	1
URs Allende Piedras Negras	126.0	1
URs Alto Río San Pedro	11.0	1
URs Área Metropolitana de Monterrey	0.8	1
URs Bajo Río Bravo	68.4	1
URs Bajo Río Conchos	10.9	1
URs Bocoyna	0.2	1
URs Cañón del Derramadero	15.0	1
URs Carichi Nonoava	0.8	1
URs Cerro Colorado la Partida	5.5	1
URs Chihuahua Sacramento	44.5	1
URs China General Bravo	1.0	1
URs Citricola Norte	106.0	1
URs Cuatrocienegas	7.1	1
URs Cuatrocienegas Ocampo	48.6	1
URs Hidalgo	3.8	1
URs Jimenez Camargo	559.0	1
URs Laguna de Mexicanos	21.4	1
URs Lampazos Anáhuac	63.0	1
URs Lampazos Villaldama	6.0	1
URs Manuel Benavides	0.7	1
URs Meoqui Delicias	220.9	1
URs Monclova	27.0	1
URs Paredón	22.4	1
URs Parral Valle del Verano	8.8	1
URs Región Carbonífera	4.9	1
URs Región Manzanera Zapaliname	68.5	1
URs Sabinas Paras	15.0	1
URs Saltillo Ramos Arizpe	21.3	1
URs Santa Fe del Pino	0.8	1
URs Valle de Juárez	143.4	1
URs Valle de Zaragoza	0.1	1
Total	**1655.3**	

Table 16: US Municipalities Demand Sites and Priority Levels

Demand Site	Expression or Demand Priority Level
Below Conchos Municipal	1
Brownsville	Key\Priorities\Municipal
City of Balmorhea	1
Del Rio	Key\Priorities\Municipal
Eagle Pass	Key\Priorities\Municipal
El Paso	Key\Priorities\Municipal
Laredo	Key\Priorities\Municipal
McAllen	Key\Priorities\Municipal
Muni Maverick	Key\Priorities\Municipal
Water Master Section 2 Municipal	1
Water Master Section 5 Municipal	1
Water Master Section 6 Municipal	1
Water Master Section 7 Municipal	1
Water Master Section 8 Municipal	1
Water Master Section 9 to 13 Municipal	1

Table 17: US Irrigation Demand Priority Levels

Demand Site	Expression or Demand Priority Level
AG EPCWID No.1	Key\Priorities\Municipal
Below Conchos Agriculture	1
Comanche Creek Water Rights AG	1
Coyanosa Draw Water Rights AG	1
Forgotten River Agriculture	1
Joe B Chandler et al Estate	1
John Edwards Robbins	1
Mattie Banner Bell	1
NM Leasburg Diversion	1
NM Mesilla Diversion	1
NM Percha Diversion	1
Red Bluff Power Control	1
Red Bluff Ward WID 2	1
Red Bluff Water Pecos WID 3	1
Red Bluff Water Power Loving	1
Red Bluff Water Reeves WID2	1
Red Bluff WID 1	1
Red Bluff WID 2	1
Red Bluff WID 2	1
Red Bluff WID 3	1
Sandia Creek Water Rights AG	1
Six Shooter Draw Water Rights	1
The Nature Conservancy	1
Water Master Section 2 Agriculture	1
Water Master Section 3 4 Agriculture	1
Water Master Section 5 Agriculture	1
Water Master Section 6 Agriculture	1
Water Master Section 7 Agriculture	1
Water Master Section 8 Agriculture	1
Water Master Section 9 to 13 Agriculture	1
Water Master Section1 Agriculture	1
Wilson Harden Cy Banner	1
Wilson Hardin Cy Banner	1

Table 18: US Other Demand Sites Priority Levels

Demand Sites	Expression or Demand Priority Level
Below Conchos Other	1
Brewster CO GW Demand	1
Cameron Co GW Demand	1
Crane CO GW Demand	1
Crockett Co GW Demand	1
Culberson Co GW Demand	1
Dimmit Co GW Demand	1
Forgotten River Industrial	1
Forgotten River Other	1
Hidalgo CO GW Demand	1
Hudspeth Co GW Demand	1
Jeff Davis Co GW Demand	1
Jim Hogg CO GW Demand	1
Kinney Co GW Demand	1
Loving Co GW Demand	1
Maverick Co GW Demand	1
Pecos Co GW Demand	1
Presidio Co GW Demand	1
Reeves Co GW Demand	1
Starr CO GW Demand	1
Terrell Co GW Demand	1
Upton Co GW Demand	1
Val Verde Co GW Demand	1
Ward Co GW Demand	1
Water Master Section 2 Other	1
Water Master Section 3 4 Mining	1
Water Master Section 3 4 Other	1
Water Master Section 5 Mining	1
Water Master Section 6 Mining	1
Water Master Section 7 Mining	1
Water Master Section 9 to 13 Mining	1
Webb Co GW Demand	1
Zapata CO GW Demand	1

Appendix D. New Mexico and Texas Sections

Table 19: Texas Watermaster Sections (Brandes 2003)

Region M Regional Water Plan		WEAP Model	
River Reaches used by the Texas Watermaster		Texas Watermaster Sections	Description
Middle Rio Grande	Reach 1	1	Amistad Dam to IBWC Streamflow Gage at Del Rio, Texas
	Reach 2	2	IBWC Streamflow Gage at Del Rio, Texas to IBWC Streamflow Gage at Eagle Pass, Texas
	Reach 3	3	IBWC Streamflow Gage at Eagle Pass, Texas to IBWC Streamflow Gage at El Indio, Texas
	Reach 4	4	IBWC Streamflow Gage at El Indio, Texas to IBWC Streamflow Gage at Laredo, Texas
	Reach 5	5	IBWC Streamflow Gage at Laredo, Texas to San Ygnacio, Texas (at the headwaters of Falcon Reservoir)
	Reach 6	6	San Ygnacio, Texas (at the headwaters of Falcon Reservoir) to Falcon Dam
Lower Rio Grande	Reach 1	7	Falcon Dam to the IBWC Streamflow Gage at Rio Grande City, Texas
	Reach 2	8	IBWC Streamflow Gage at Rio Grande City, Texas to Anzalduas Dam
	Reach 3	9	Anzalduas Dam to Retamal Dam
	Reach 4	10	Retamal Dam to the IBWC Streamflow Gage at San Benito, Texas
	Reach 5	11	IBWC Streamflow Gage at San Benito, Texas to Cameron County WCID No. 6 River Diversion Point
	Reach 6	12	Cameron County WCID No. 6 River Diversion Point to IBWC Streamflow Gage near Brownsville, Texas
	Reach 7	13	IBWC Streamflow Gage near Brownsville, Texas to the Gulf of Mexico

Figure 3-3 Flow Distribution Along the RGCP

Inflow / Outflow	Location	Average Flow (cfs) Mar-Oct	Nov-Feb	Annual
	Caballo Dam Release[b]	1,301	167	923
Percha Lateral/Arrey Canals (350 cfs)[a]	Water Diversion at Percha Dam	*(160)*	*(20)*	*(114)*
	Downstream Release[c]	1,141	147	809
Garfield, Hatch, Angostura and Rincon Drains	Return Flows[d]	78	16	58
	Seldon Canyon Flow[b]	1,219	163	867
Leasburg Canal (625 cfs)[a]	Water Diversion at Leasburg Dam[b]	*(265)*	*(13)*	*(181)*
	Downstream Release[c]	954	150	686
Seldon & Picacho Drains	Return Flows[e]	80	4	54
East and West Canals (950 cfs)[a]	Water Diversion at Mesilla Dam[b]	*(455)*	*(27)*	*(312)*
	Downstream Release[c]	579	127	428
Del Rio, La Mesa, Anthony, East, Montoya Drains, other	Return Flows[d]	196	97	163
	Upstream of Amer. Dam[b]	774	224	591
American Canal (1,200 cfs)[a]	Water Diversion at American Dam[b]	*(595)*	*0*	*(397)*
	Downstream Release[c]	179	224	194
Acequia Madre	Water Diversion at International Dam[b]	*(102)*	*0*	*(68)*

a. Maximum diversion capacities, in parenthesis, from U.S. Bureau of Reclamation (www.usbr.gov)

b. Highlighted values indicate stream flows. Values as reported in the Draft EIS, El Paso-Las Cruces Regional Sustainable Water Project (USIBWC & EPWU/PSB, 2000: Table 3.3-17).

c. Releases from dams were calculated as the difference between upstream flow and diverted flow.

d. Return flows were calculated as the difference between upstream and downstream flows.

e. Mesilla Valley return flows represent 30% of the diverted flow (USIBWC & EPWU/PSB, 2000, p. 3-10)

Figure 33: New Mexico Diversions Data (IBWC DEIS 2003a)

Appendix E. Texas Reservoir Engineering Data

Table 20: Texas Reservoir Engineering Data (TWDB 1971)

Texas Reservoir Number	Units	23080	23020	23060	23040	23043	23050	23070
Reservoir		**Anzalduas Channel Dam**	**Lake Balmorhea**	**Casa Blanca Lake**	**San Esteban Lake**	**Red Bluff**	**Amistad**	**Falcon**
Owner		IBWC/CILA	Texas	Texas	Texas	Texas	IBWC/CILA	IBWC/CILA
Dam Length	ft	524.0	4,000.0	5,000.0	400.0	9,230.0	32,000.0	26,294.0
	m	1,719.2	13,123.4	16,404.2	1,312.3	30,282.2	104,986.9	86,266.4
Dam Top Elevation	ft msl	106.0	3,192.0	467.0		2,856.0	1,152.3	323.0
	m msl	347.8	10,472.4	1,532.2		9,370.1	3,780.5	1,059.7
Elevation at Top of Flood Pool	ft msl						1,140.4	314.2
	m msl						3,741.5	1,030.8
Elevation at Top of Conservation Pool	ft msl	104.5	3,187.0	446.5	4,451.0	2,842.0	1,117.0	301.2
	m msl	342.8	10,456.0	1,464.9	14,603.0	9,324.1	3,664.7	988.2
Elevation at top of Dead Zoon (Feet MSL)	ft msl					2,763.7	930.0	204.3
	m msl					9,067.3	3,051.2	670.4
Storage at Top of Flood Pool	ac-ft						5,249,700.0	4,080,800.0
	MCM						6,472.9	5,031.6
Storage at Top of Conservation Pool-Original	ac-ft	13,910.0	7,707.0	20,000.0	18,770.0	310,000.0	3,505,400.0	2,767,400.0
	MCM	17.2	9.5	24.7	23.1	382.2	4,322.2	3,412.2

Texas Reservoir Number	Units	23080	23020	23060	23040	23043	23050	23070
Reservoir		**Anzalduas Channel Dam**	**Lake Balmorhea**	**Casa Blanca Lake**	**San Esteban Lake**	**Red Bluff**	**Amistad**	**Falcon**
Storage at Top of Conservation Pool-Surveyed	ac-ft	13,910.0	6,350.0	20,000.0		289,670.0	3,505,400.0	2,668,000.0
	MCM	17.2	7.8	24.7	0.0	357.2	4,322.2	3,289.6
Storage at top of Dead Zoon	ac-ft					3,000.0	8,000.0	2,820.0
	MCM					3.7	9.9	3.5
Surface Area at Top of Conservation Pool-Original	ac	1,472.0	573.0	1,680.0	762.0	11,193.0	64,900.0	86,843.0
Surface Area at Top of Conservation Pool-Surveyed	ac			1,680.0				
Date of Last Survey		34,547.0	1,948.0	28,642.0			34,608.0	
Drainage Area	sq mi	16,842.0	22.0	117.0		20,720.0	126,423.0	164,482.0
Main Purposes		irrigation	irrigation	irrigation, recreation		irrigation	flood control, hydroelectric, irrigation, recreation	flood control, water supply, irrigation, hydroelectric
Year of Completion		1960	1917	1951	1911	1936	1969	1954
Basin ID		23	23	23	23	23.0	23	23
River Basin		Rio Grande	Rio Grande	Rio Grande	Rio Grande	Rio Grande	Rio Grande	Rio Grande
Stream		Rio Grande River	Sandia Creek	Chacon Creek	Alamito	Pecos River	Rio Grande River	Rio Grande River
County		Hidalgo	Reeves, Loving	Webb	Presidio	Reeves, Loving	Val Verde	Starr
Nearest Town		Hidalgo	Balmorhea	Laredo	Marfa	Oria	Del Rio	Roma
Direction to Nearest Town			2 miles SW	0 miles	10 miles S	5 miles S	12 miles NW	13 road miles (19 river miles) upstream from Roma

Texas Reservoir Number	Units	23080	23020	23060	23040	23043	23050	23070
Reservoir		**Anzalduas Channel Dam**	**Lake Balmorhea**	**Casa Blanca Lake**	**San Esteban Lake**	**Red Bluff**	**Amistad**	**Falcon**
Water Planning Region		M	E	M	E	F	J	M
Dam Central Latitude		26.1	31.0	27.5		31.9	29.4	26.6
Dam Central Longitude		-98.3	-103.7	-99.4		-103.9	-101.1	-99.2
Reservoir Gage						8410000	8888888	9999999
Upstream USGS Streamflow Gage								8459200
Downstream USGS Streamflow Gage				8459200		8446500		
Major Water Rights			A60 or P57	C2744		C5438		

Appendix F. Reservoir Area-Elevation Capacity Curves

Table 21: Anzalduas Dam Area-Elevation Capacity Curve Data (TWDB 1971)

Elevation (ft)	Area (acres)	Capacity (acre-ft)	Capacity (Mm^3)	Elevation (m)
84	70	87.5	0.108	275.591
85	140	250	0.308	278.871
86	200	500	0.617	282.152
87	270	700	0.863	285.433
88	310	800	0.987	288.714
89	355	1150	1.419	291.995
90	390	1500	1.850	295.276
91	450	1900	2.344	298.556
92	485	2300	2.837	301.837
93	520	2750	3.392	305.118
94	575	3400	4.194	308.399
95	645	3900	4.811	311.680
96	795	4700	5.797	314.961
97	940	5400	6.661	318.241
98	1060	6660	8.215	321.522
98.5	1950	7050	8.696	323.163

Table 22: Casa Blanca Lake Area-Elevation Capacity Curve Data (TWDB 1971)

Elevation (ft)	Area (acres)	Capacity (acre-ft)	Capacity (Mm^3)	Elevation (m)
423	40	300	1387.795	0.370
424	120	900	1391.076	1.110
426	198	1500	1397.638	1.850
427	230	1900	1400.919	2.344
428	280	2250	1404.199	2.775
430	370	3000	1410.761	3.700
432	480	3900	1417.323	4.811
433	530	4350	1420.604	5.366
435	660	5550	1427.165	6.846
436	730	6300	1430.446	7.771
438	900	7800	1437.008	9.621
439	1000	8850	1440.289	10.916
440	1080	9900	1443.570	12.211
441	1180	10800	1446.850	13.322
442	1240	12000	1450.131	14.802
443	1560	13500	1453.412	16.652
445	1530	16500	1459.974	20.352
450	1950	25200	1476.378	31.084

Table 23: Red Bluff Area-Elevation Capacity Curve Data (TWDB 1971)

Elevation (ft)	Storage (ac-ft)	Storage (Mm^3)	Elevation (m)
2792	23500	28.987	851.002
2793	24758	30.539	851.306
2794	26130	32.231	851.611
2795	27618	34.066	851.916
2796	29220	36.042	852.221
2797	30938	38.161	852.526
2798	32771	40.422	852.830
2799	34718	42.824	853.135
2800	36780	45.367	853.440
2801	38981	48.082	853.745
2802	41348	51.002	854.050
2803	43879	54.124	854.354
2804	46575	57.449	854.659
2805	49436	60.978	854.964
2806	52462	64.711	855.269
2807	55653	68.647	855.574
2808	59009	72.787	855.878
2809	62530	77.130	856.183
2810	66218	81.679	856.488
2811	70073	86.434	856.793
2812	74094	91.394	857.098
2813	78280	96.557	857.402
2814	82632	101.925	857.707
2815	87149	107.497	858.012
2816	91832	113.273	858.317
2817	96680	119.253	858.622
2818	101690	125.433	858.926
2819	106870	131.822	859.231
2820	112230	138.434	859.536
2821	117790	145.292	859.841
2822	123560	152.409	860.146
2823	129560	159.810	860.450
2824	135770	167.470	860.755
2825	142210	175.413	861.060
2826	148860	183.616	861.365
2827	155730	192.090	861.670
2828	162820	200.836	861.974
2829	170200	209.939	862.279
2830	177660	219.140	862.584
2831	185430	228.725	862.889
2832	193490	238.666	863.194
2833	201830	248.954	863.498
2834	210450	259.586	863.803
2835	219350	270.564	864.108

Elevation (ft)	Storage (ac-ft)	Storage (Mm^3)	Elevation (m)
2836	228520	281.875	864.413
2837	237980	293.544	864.718
2838	247720	305.558	865.022
2839	257740	317.918	865.327
2840	268040	330.622	865.632
2841	278660	343.722	865.937
2842	289670	357.303	866.242

Table 24: Amistad Area-Elevation Capacity Curve Data (TWDB 1971)

Elevation (ft)	Area (acres)	Construction Capacity (acre-ft)	Storage (Mm^3)	Elevation (m)
955	2,000	60,000	74.009	291.084
980	5,100	120,000	148.018	298.704
995	5,900	180,000	222.027	303.276
1,010	7,500	300,000	370.045	307.848
1,025	10,500	420,000	518.062	312.420
1,035	13,000	540,000	666.080	315.468
1,050	19,000	780,000	962.116	320.040
1,060	24,000	1,020,000	1,258.151	323.088
1,080	38,000	1,560,000	1,924.232	329.184
1,085	41,000	1,800,000	2,220.267	330.708
1,095	49,000	2,220,000	2,738.330	333.756
1,105	55,000	2,700,000	3,330.401	336.804
1,110	60,000	3,000,000	3,700.446	338.328
1,120	68,000	3,720,000	4,588.552	341.376
1,130	76,000	4,380,000	5,402.650	344.424
1,135	80,000	4,740,000	5,846.704	345.948
1,140	85,000	5,100,000	6,290.757	347.472
1,145	88,900	5,640,000	6,956.838	348.996

Table 25: Falcon Area-Elevation Capacity Curve Data (TWDB 1971)

Elevation (ft)	Area (acres)	Construction Capacity (acre-ft)	Storage (Mm^3)	Elevation (m)
214	2,500	50,000	61.674	65.227
228	5,000	100,000	123.348	69.494
240	10,000	200,000	246.696	73.152
245	13,500	250,000	308.370	74.676
254	21,400	400,000	493.393	77.419
258	25,500	500,000	616.741	78.638
262	30,000	600,000	740.089	79.858
268	35,500	640,000	789.428	81.686
280	50,000	1,350,000	1,665.200	85.344
284	55,500	1,550,000	1,911.897	86.563
288	62,000	1,800,000	2,220.267	87.782
298	80,000	2,500,000	3,083.705	90.830
304	90,000	3,000,000	3,700.446	92.659
309	102,000	3,500,000	4,317.186	94.183
318	122,000	4,500,000	5,550.668	96.926
322	132,000	5,000,000	6,167.409	98.146
326	143,000	5,600,000	6,907.498	99.365
330	150,000	6,200,000	7,647.587	100.584

Table 26: Elephant Butte Area-Elevation Capacity Curve Data (USBR 2006b)

Capacity equations are of the form $y = a_1+a_2x+a_3x^2$ where y is capacity and x is the elevation above an elevation base.					
Equation Number	**Base Elevation (ft)**	**Capacity Base (ac-ft)**	**Coefficient A1 (Intercept)**	**Coefficient A2 (1st Term)**	**Coefficient A3 (2nd Term)**
1	4245	0	0	0	6.28
2	4250	157	157	62.8	37.94
3	4260	4579	4579	821.6	64.25
4	4270	19220	19220	2106.5999	22.75
5	4280	42561	42561.0004	2561.6	80.445
6	4290	76221	76221.4994	4170.5002	94.615
7	4300	127388	127387.9991	6062.8004	68.555
8	4310	194871	194871.4989	7433.9009	106.4599
9	4320	279856	279856.4988	9563.1009	80.2799
10	4330	383515	383515.5007	11168.6988	93.8851
11	4340	504591	504590.9984	13046.4024	86.8398
12	4350	643744	643744.0024	14784.1988	149.0251
13	4360	806488	806488.4977	17764.7016	154.5749
14	4370	999593	999593.0066	20856.1942	173.3407
15	4380	1225489	1225489.969	24323.0143	173.2287
16	4390	1486042	1486042.001	27787.6009	213.1648
17	4400	1785234	1785234.491	32050.9037	280.9696

Table 27: Caballo Area-Elevation Capacity Curve Data (USBR 2006a)

Capacity equations are of the form $y = a_1+a_2x+a_3x^2$ where y is capacity and x is the elevation above an elevation base. The capacity equation coefficients for the reservoir are shown below (e = 0.000001)					
Equation Number	**Base Elevation (ft)**	**Capacity Base (ac-ft)**	**Coefficient A1 (Intercept)**	**Coefficient A2 (1st Term)**	**Coefficient A3 (2nd Term)**
1	4115	0	0	0	10.987
2	4120	274	274.675	109.87	75.079
3	4125	2701	2701.001	860.6599	68.549
4	4130	8718	8718.0253	1546.1502	49.152
5	4135	17677	17677.5744	2037.6697	68.1331
6	4140	29569	29569.2497	2739.0004	101.4479
7	4145	45700	45700.4496	3733.4797	112.09
8	4150	67170	67170.1021	4854.3797	103.413
9	4155	94027	94027.3275	5888.5108	114.2418
10	4160	126325	126325.9282	7030.9308	70.9859
11	4165	163255	163255.2361	7740.7903	102.5679
12	4170	204523	204523.8896	8766.6716	120.0327
13	4175	251358	251358.0622	9967.0008	113.6999
14	4180	304035	304035.5671	11103.9914	107.003

Appendix G. WEAP Reservoir Inputs

Table 28: Parameters Entered into WEAP for the Reservoirs

Owner	River	Reservoir	Storage Capacity	Initial Storage	Volume Elevation Curve	Net Evaporation	Top of Conservation	Top of Buffer	Top of Inactive	Buffer Coefficient	Priority
IBWC/CILA	Rio Grande/Bravo	Amistad	X	X	X	X	X		X		99
IBWC/CILA	Rio Grande/Bravo	Falcon	X	X	X	X	X		X		99
IBWC/CILA	Rio Grande/Bravo	Anzalduas Dam	X	X	X						99
Mexico	Rio San Juan	El Cuchillo	X	X	X	X	X		X		99
Mexico	Rio San Pedro	F. Madero	X	X	X	X	X	X	X	X	99
Mexico	Rio Conchos	La Boquilla	X	X	X	X	X	X	X	X	99
Mexico	Rio San Rodrigo	La Fragua	X		X		X		X		99
Mexico	Rio Alamos	Las Blancas	X				X		X		99
Mexico	Rio Conchos	Luis L. Leon	X	X	X	X	X	X	X	X	99
Mexico	Rio San Juan	Marte R. Gomez	X	X	X	X	X		X		99
Mexico	Rio Florido	Pico del Aguila	X	X	X	X	X	X	X		99
Mexico	Rio Florido	San Gabriel	X	X	X	X	X	X	X	X	99
Mexico	Rio Salado	V. Carranza	X	X	X	X	X		X		99
US	Rio Grande/Bravo	Caballo	X	X	X	X	X		X		99
US	Rio Grande/Bravo	Elephant Butte	X	X	X	X	X		X		99
US	Toyah Creek	Lake Balmorhea	X								99
US	Pecos River	Red Bluff	X				X		X		99
US	Alamito Creek	San Esteban Lake	X								99
X = Data has been entered into this field in WEAP. If the field is blank then no value or expression as been entered to date.											

Appendix H. WEAP Model Flow Diagram

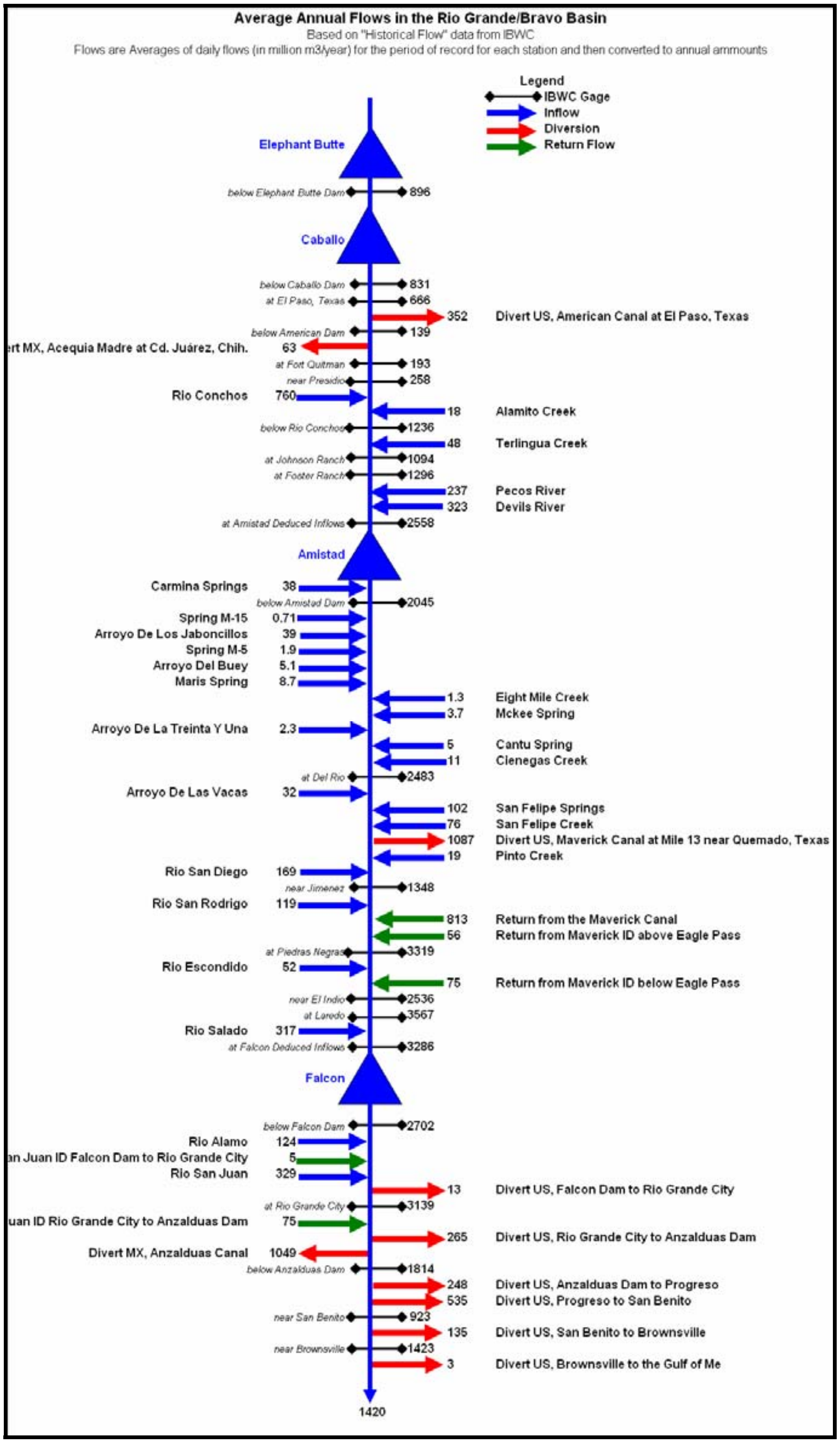

Figure 34: Average Annual Flows for the Rio Grande/Bravo Basin

Appendix I. Evaporation Losses WEAP Inputs

Table 29: WEAP Inputs for Combined Evaporation Losses per Reach (TCEQ 2005a)

Level 1	Level 2	Level 3	Level 4...	Evaporation %
Supply and Resources	River	Alamito Crk	Reaches\Below Alamito Crk Headflow	9%
Supply and Resources	River	Arroyo Las Vacas	Reaches\Below Arroyo Las Vacas Headflow	10%
Supply and Resources	River	Arroyo Sabinas	Reaches\Below Arroyo Sabinas Headflow	1%
Supply and Resources	River	Delaware River	Reaches\Below Delaware River Headflow	9%
Supply and Resources	River	Devils River	Reaches\Below TCEQ_Gains_1040100182 Inflow	5%
Supply and Resources	River	Devils River	Reaches\Below Devils River Headflow	6%
Supply and Resources	River	Pecos River	Reaches\Below TCEQ_Gains_1070100117 Inflow	11%
Supply and Resources	River	Pecos River	Reaches\Below TCEQ_Gains_1070100119 Inflow	30%
Supply and Resources	River	Pecos River	Reaches\Below TCEQ_Gains_1070100118 Inflow	48%
Supply and Resources	River	Pinto Crk	Reaches\Below Pinto Crk Headflow	5%
Supply and Resources	River	Rio Alamos	Reaches\Below Las Blancas	3%
Supply and Resources	River	Rio Conchos	Reaches\Below Withdrawal Node 2	17%
Supply and Resources	River	Rio Conchos	Reaches\Below Rio San Pedro Inflow	20%
Supply and Resources	River	Rio Escondido	Reaches\Below Rio Escondido Headflow	9%
Supply and Resources	River	Rio Florido	Reaches\Below Withdrawal Node 6	18%
Supply and Resources	River	Rio Grande_Rio Bravo	Reaches\Below Withdrawal Node 11	0%
Supply and Resources	River	Rio Grande_Rio Bravo	Reaches\Below TCEQ_Gains_1080100377 Inflow	1%
Supply and Resources	River	Rio Grande_Rio Bravo	Reaches\Below TCEQ_Gains_1040100177 Inflow	2%
Supply and Resources	River	Rio Grande_Rio Bravo	Reaches\Below TCEQ_Gains_1040100180 Inflow	2%
Supply and Resources	River	Rio Grande_Rio Bravo	Reaches\Below TCEQ_Gains_1090100423 Inflow	4%
Supply and Resources	River	Rio Grande_Rio Bravo	Reaches\Below TCEQ_Gains_1090100422 Inflow	5%
Supply and Resources	River	Rio Grande_Rio Bravo	Reaches\Below TCEQ_Gains_1080100382 Inflow	9%

Level 1	Level 2	Level 3	Level 4...	Evaporation %
Supply and Resources	River	Rio Grande_Rio Bravo	Reaches\Below TCEQ_Gains_1040100179 Inflow	10%
Supply and Resources	River	Rio Grande_Rio Bravo	Reaches\Below TCEQ_Gains_1080100380 Inflow	13%
Supply and Resources	River	Rio Grande_Rio Bravo	Reaches\Below TCEQ_Gains_1080100381 Inflow	14%
Supply and Resources	River	Rio Grande_Rio Bravo	Reaches\Below Return Flow Node 9	20%
Supply and Resources	River	Rio Grande_Rio Bravo	Reaches\Below TCEQ_Gains_1040100175 Inflow	46%
Supply and Resources	River	Rio Pesqueria	Reaches\Below TCEQ_Gains_2060100004 Inflow	11%
Supply and Resources	River	Rio Salado	Reaches\Below Rio Salado Headflow	2%
Supply and Resources	River	Rio Salado	Reaches\Below TCEQ_Gains_2040100011 Inflow	6%
Supply and Resources	River	Rio Salado	Reaches\Below TCEQ_Gains_2040100012 Inflow	6%
Supply and Resources	River	Rio Salinas	Reaches\Below Rio Salinas Headflow	7%
Supply and Resources	River	Rio San Diego	Reaches\Below Rio San Diego Headflow	10%
Supply and Resources	River	Rio San Juan	Reaches\Below TCEQ_Gains_2060100006 Inflow	3%
Supply and Resources	River	Rio San Juan	Reaches\Below Marte R. Gomez	3%
Supply and Resources	River	Rio San Juan	Reaches\Below El Cuchillo	13%
Supply and Resources	River	Rio San Rodrigo	Reaches\Below Rio San Rodrigo Headflow	9%
Supply and Resources	River	San Felipe Crk	Reaches\Below San Felipe Crk Headflow	1%
Supply and Resources	River	Terlingua Crk	Reaches\Below Terlingua Crk Headflow	5%

Appendix J. Historical Reservoir Storage per Subbasin

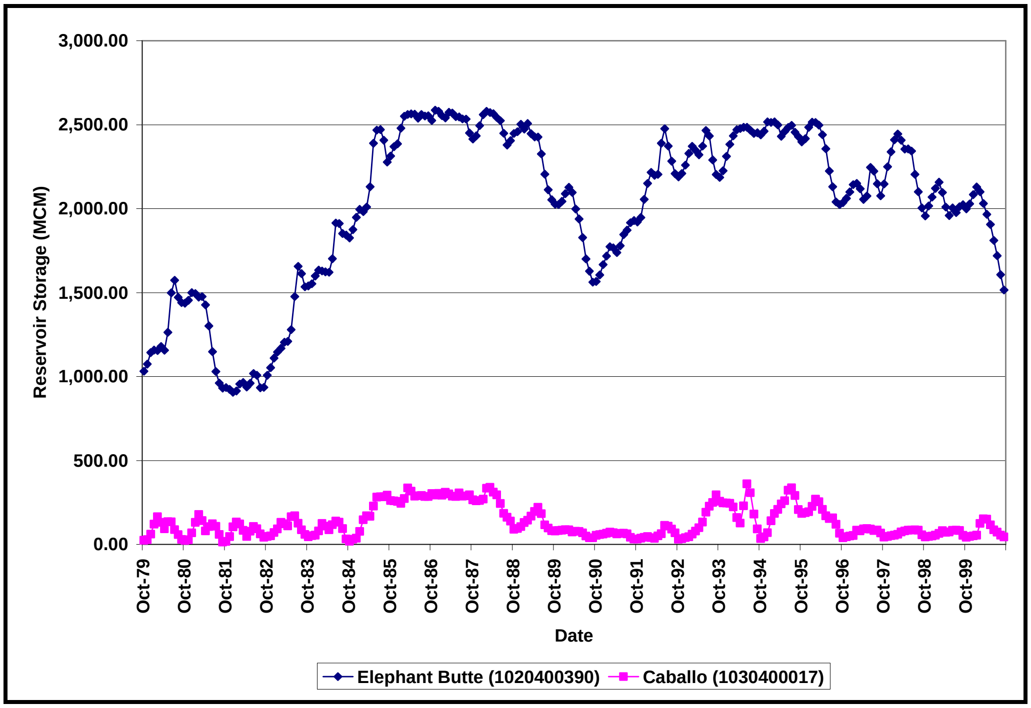

Figure 35: Upper Rio Grande/Bravo Historical Reservoir Storage

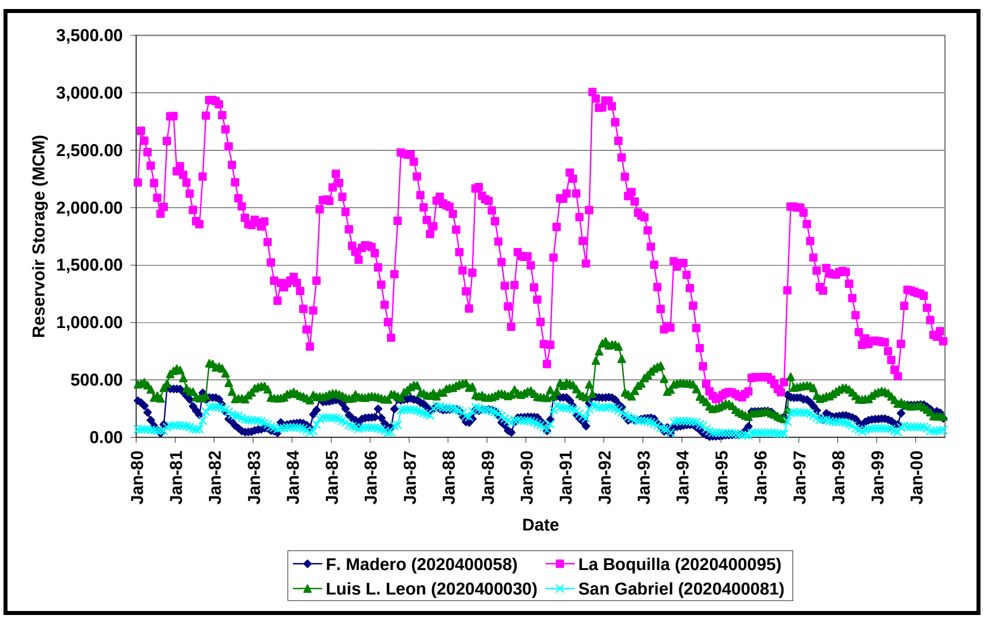

Figure 36: Rio Conchos Subbasin Historical Reservoir Storage

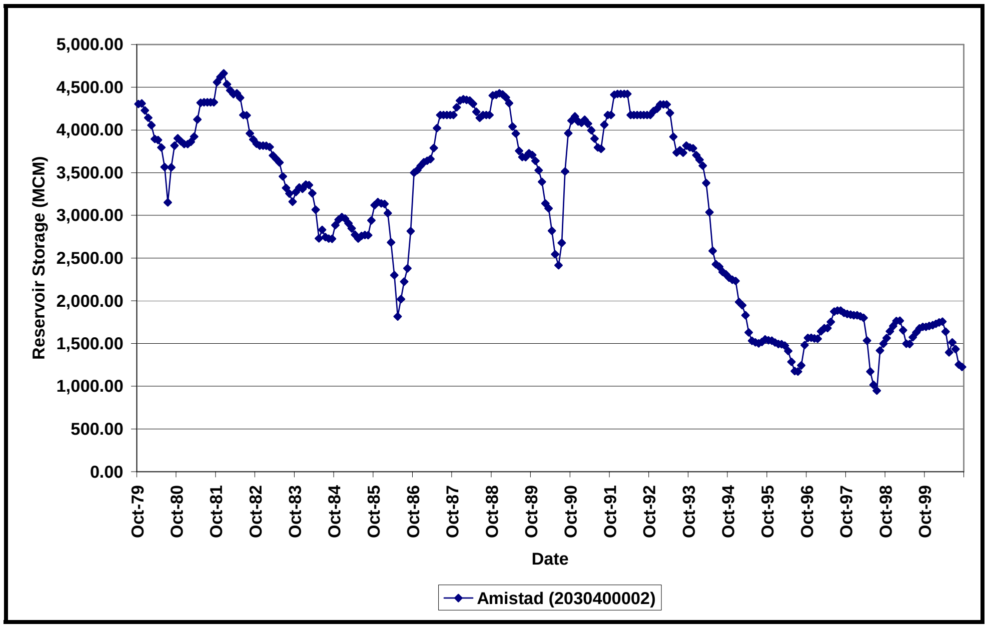

Figure 37: Middle Rio Grande/Bravo Historical Reservoir Storage

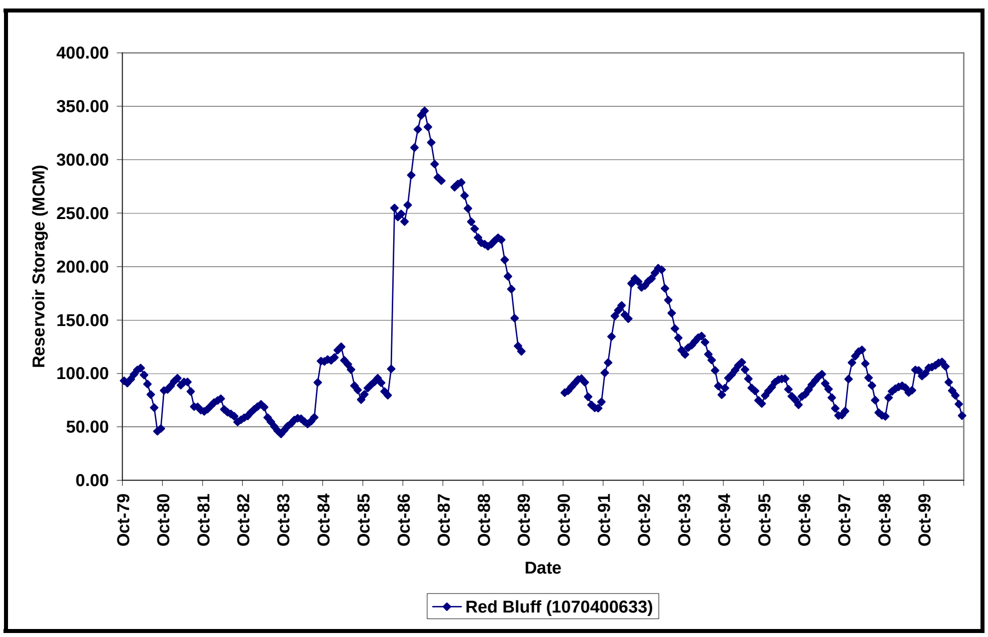

Figure 38: Pecos River Historical Reservoir Storage

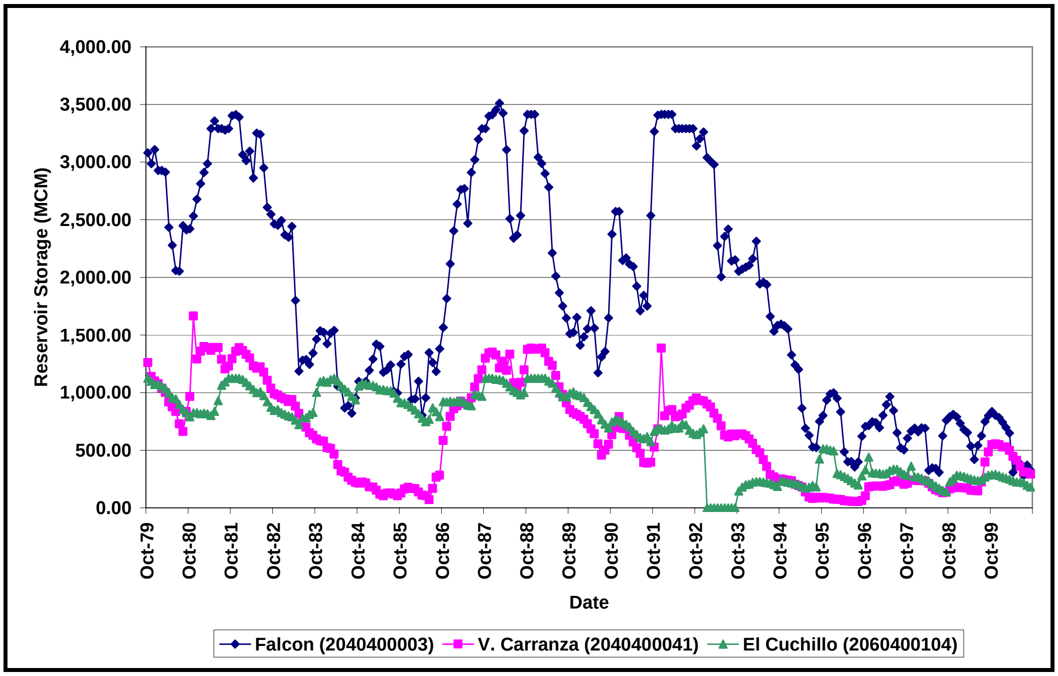

Figure 39: Lower Rio Grande/Bravo Historical Reservoir Storage

Appendix K. Rio Conchos Reservoir Testing

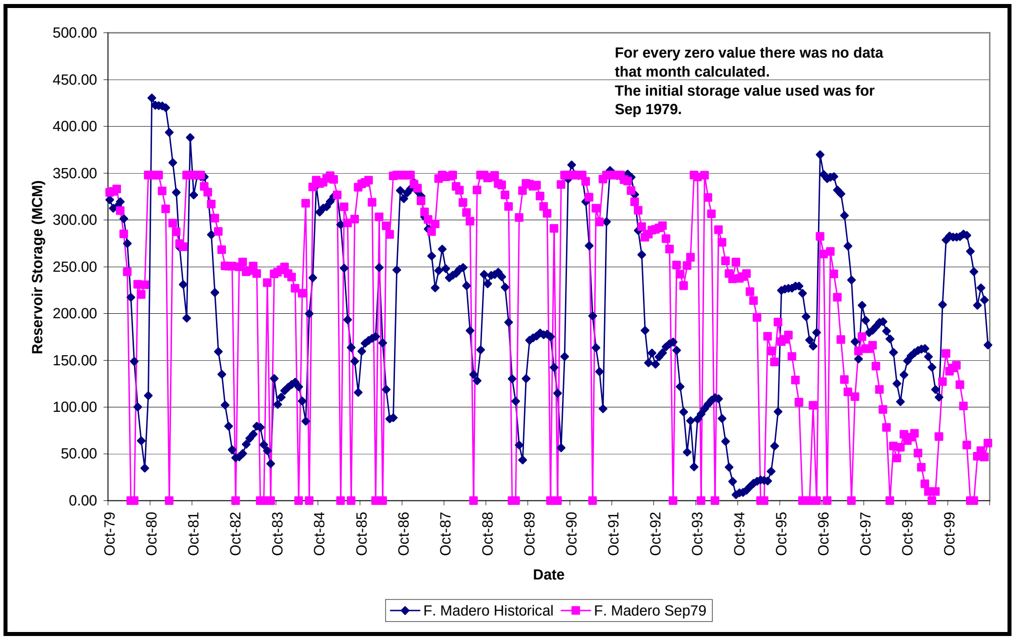

Figure 40: F. Madero Historical Data Compared to Initial Storage Value of Sep 1979

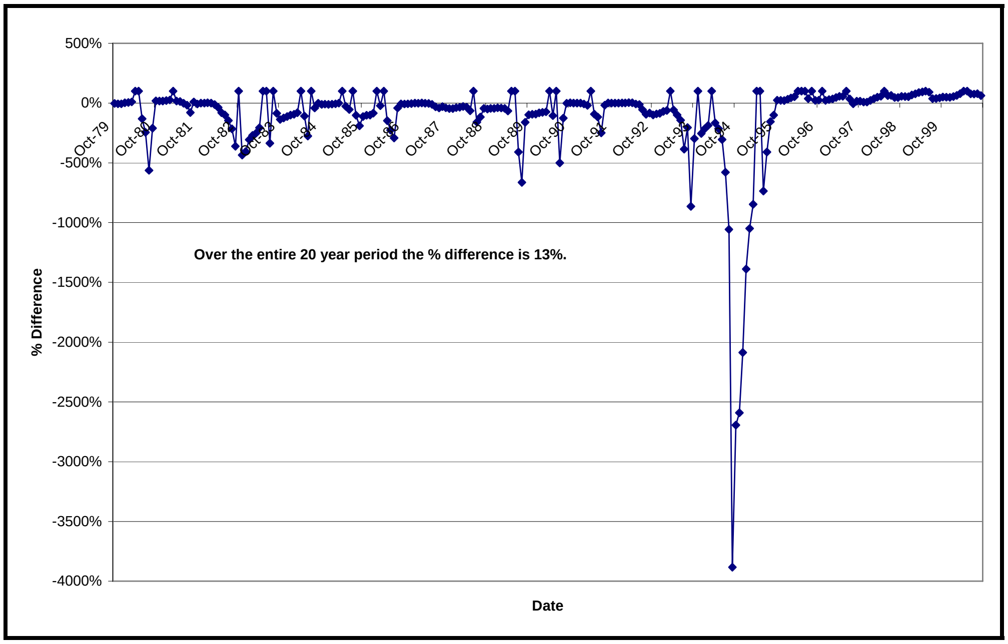

Figure 41: F. Madero Historical vs. Model Percent Difference

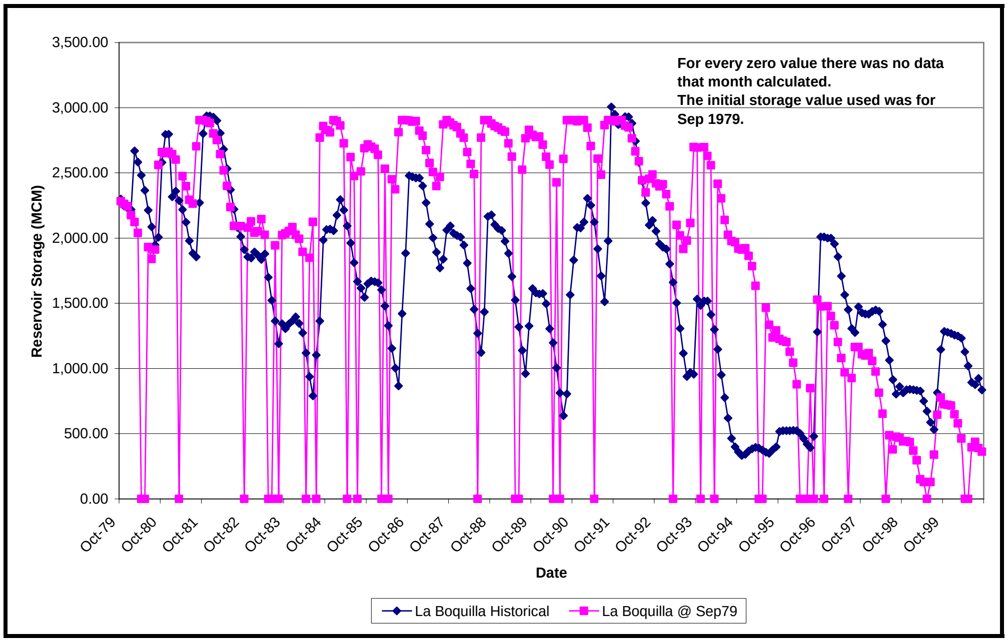

Figure 42: La Boquilla Historical vs. Modeled Reservoir Storage

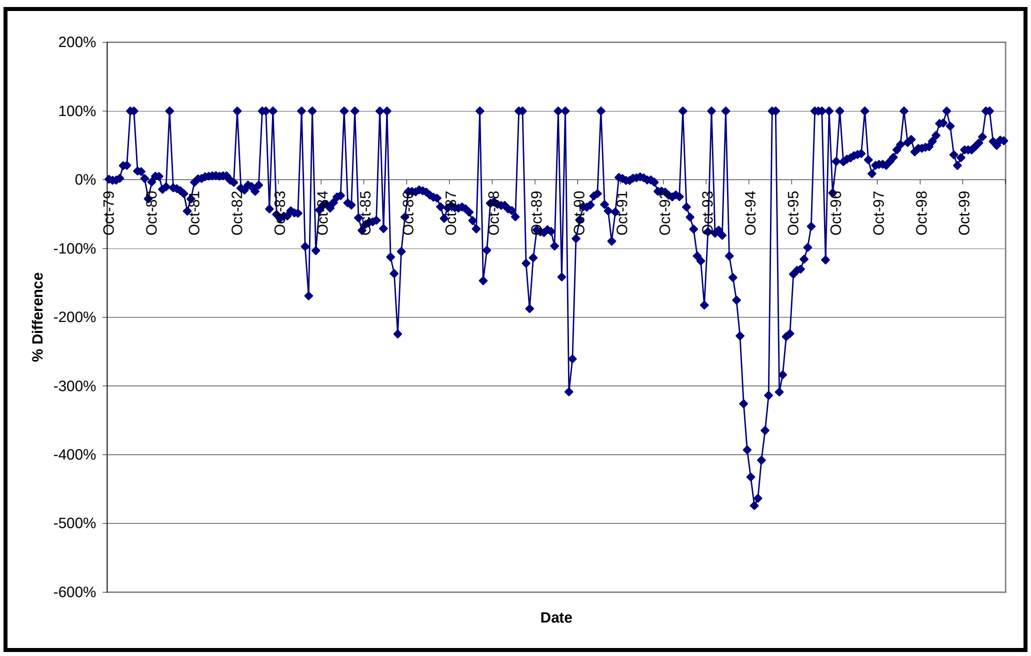

Figure 43: La Boquilla Historical vs. Modeled Reservoir Storage % Difference

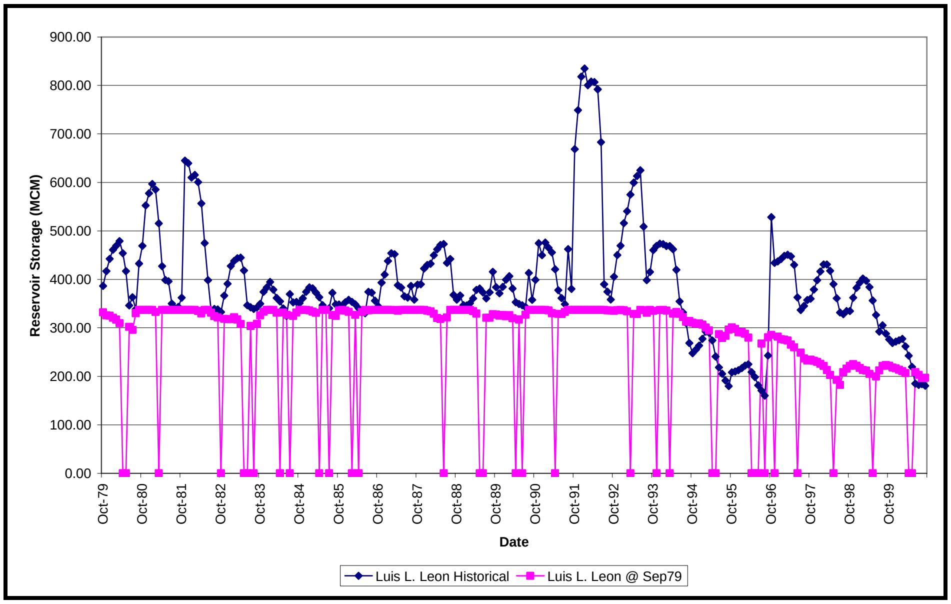

Figure 44: Luis L. Leon Historical vs. Modeled Reservoir Storage

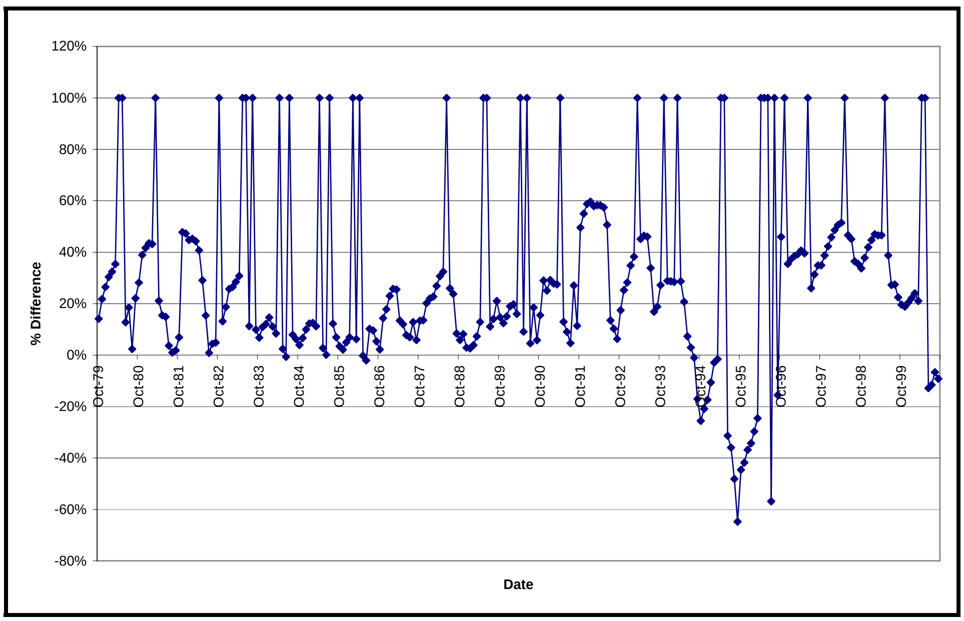

Figure 45: Luis L. Leon Historical vs. Modeled % Difference

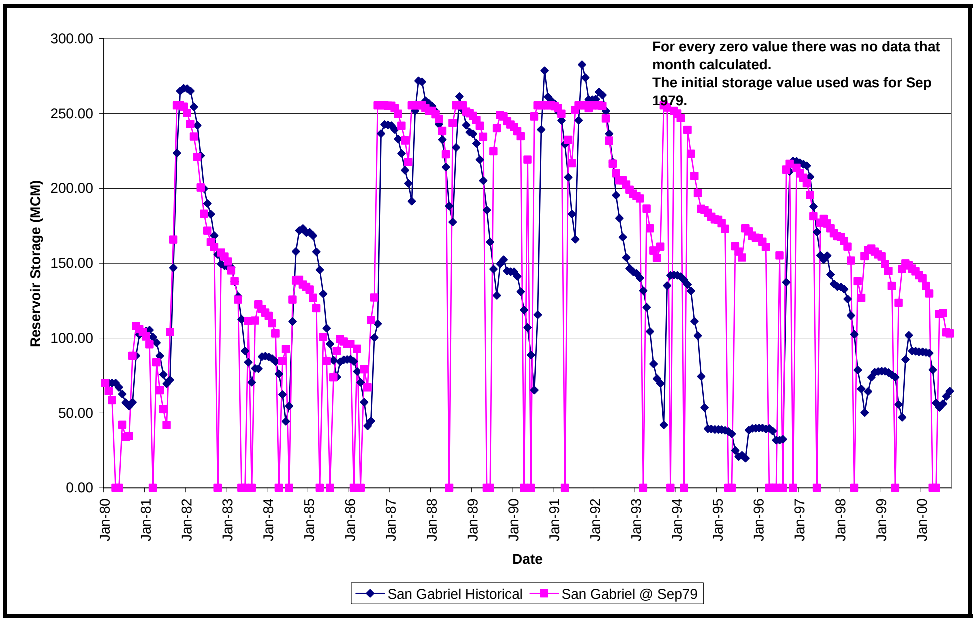

Figure 46: San Gabriel Historical vs. Modeled Reservoir Storage

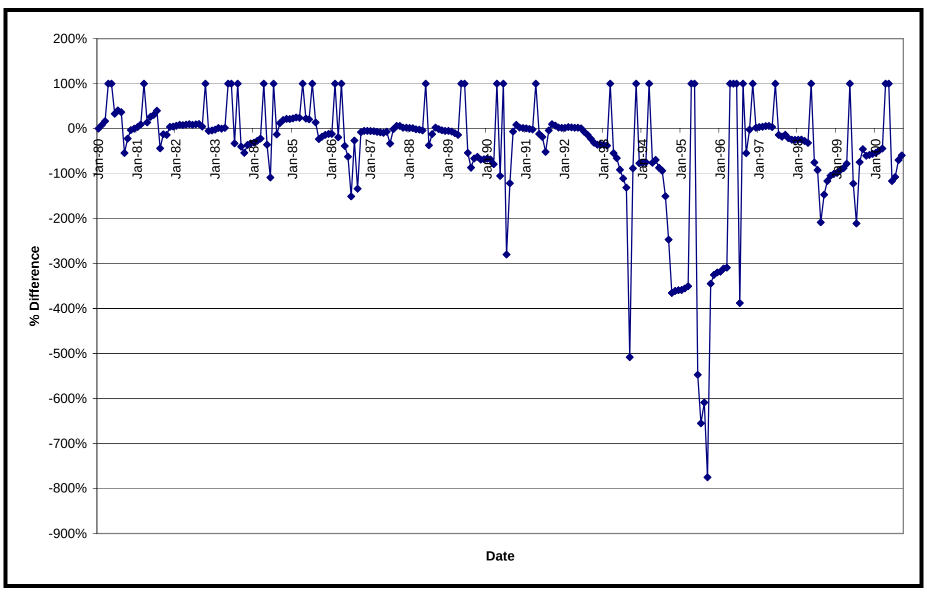

Figure 47: San Gabriel Historical vs. Modeled % Difference

Appendix L. Middle Rio Grande/Bravo Reservoir Testing

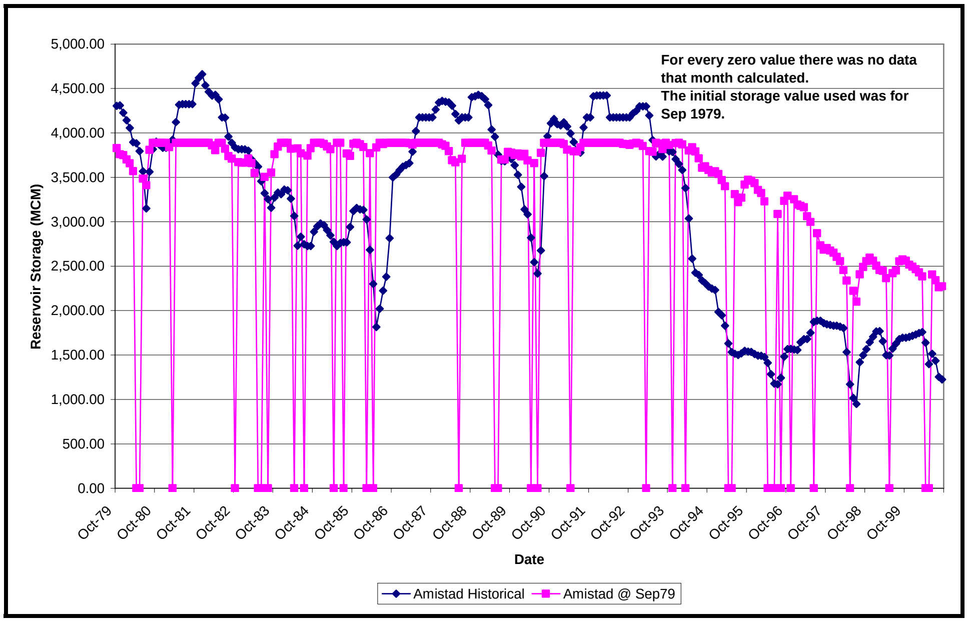

Figure 48: Amistad Historical vs. Modeled Reservoir Storage

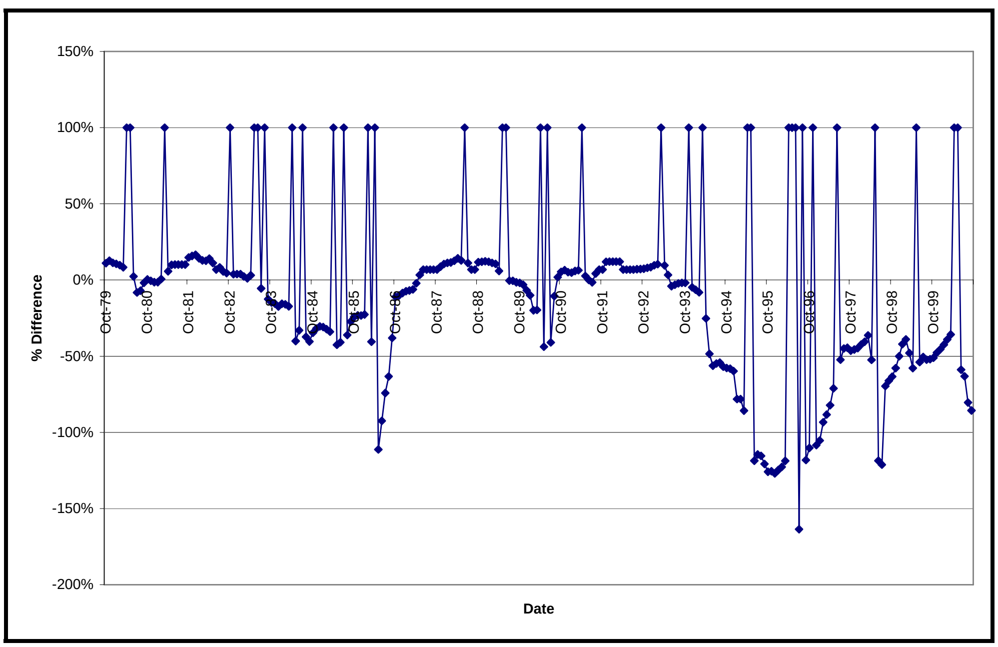

Figure 49: Amistad Historical vs. Modeled % Difference

Appendix M. Lower Rio Grande/Bravo Reservoir Testing

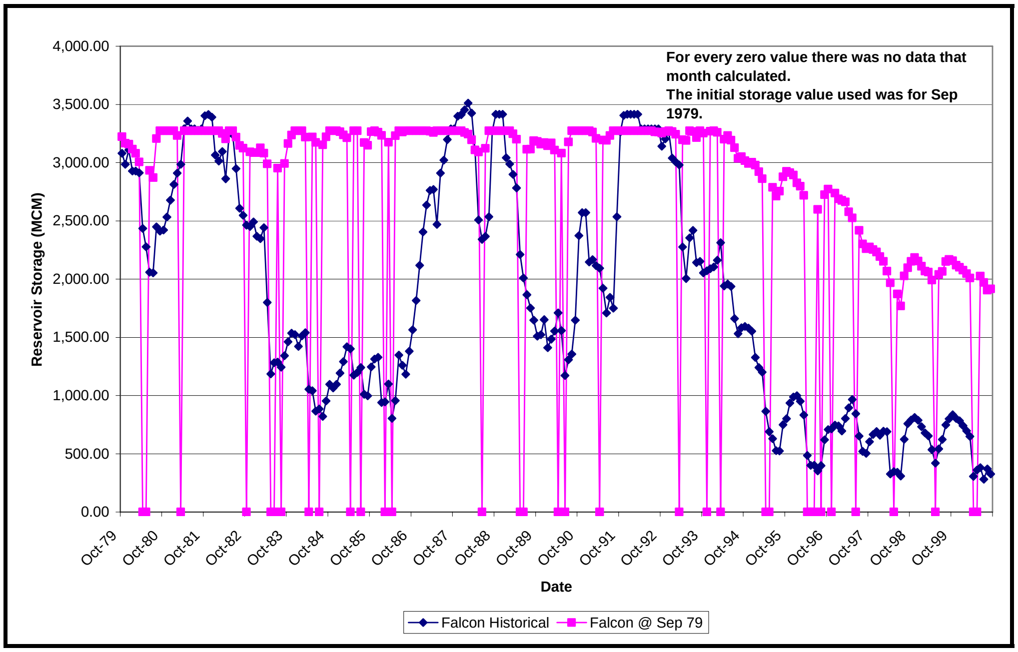

Figure 50: Falcon Historical vs. Modeled Reservoir Storage

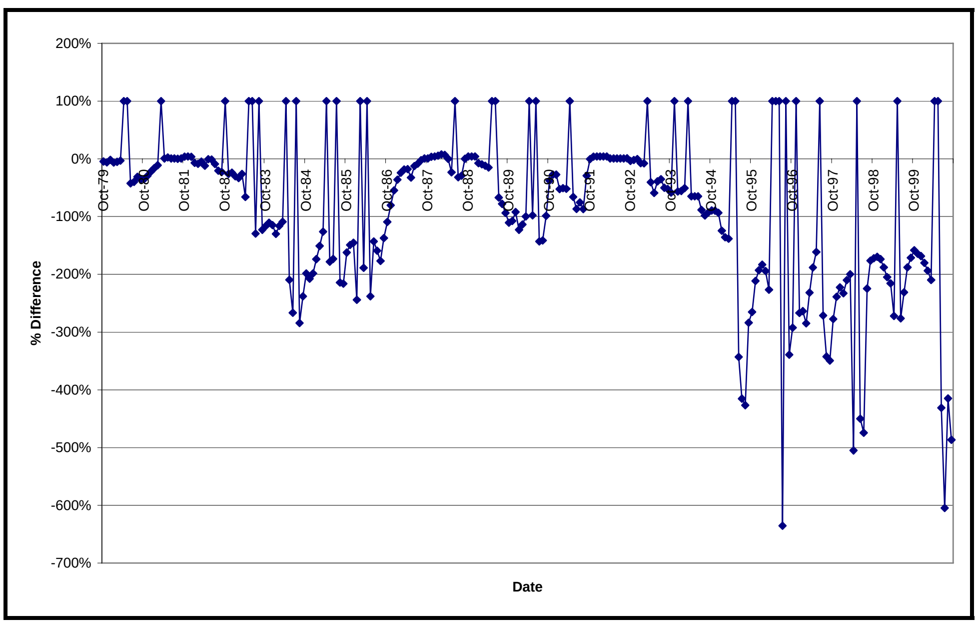

Figure 51: Falcon Historical vs. Modeled % Difference

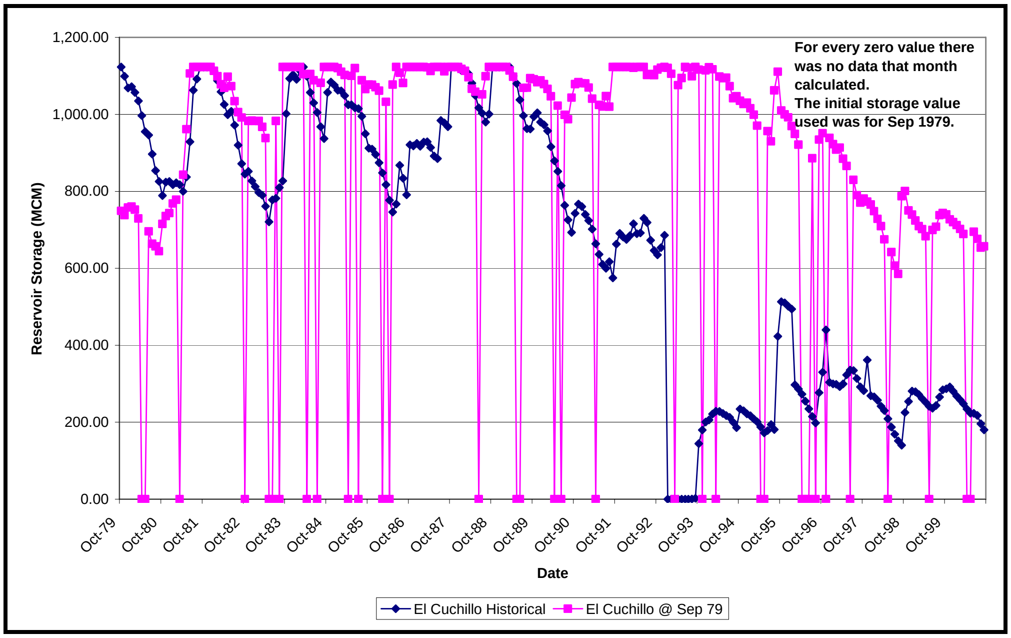

Figure 52: El Cuchillo Historical vs. Modeled Reservoir Storage

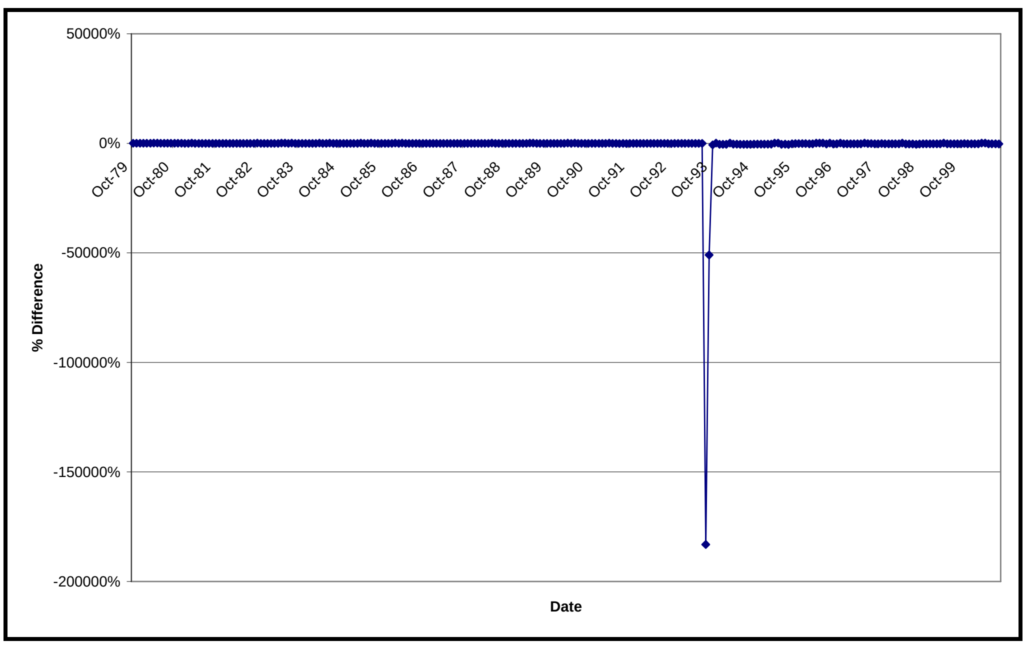

Figure 53: El Cuchillo Historical vs. Modeled % Difference

Appendix N. IBWC Gauge Comparison Tables Graphs

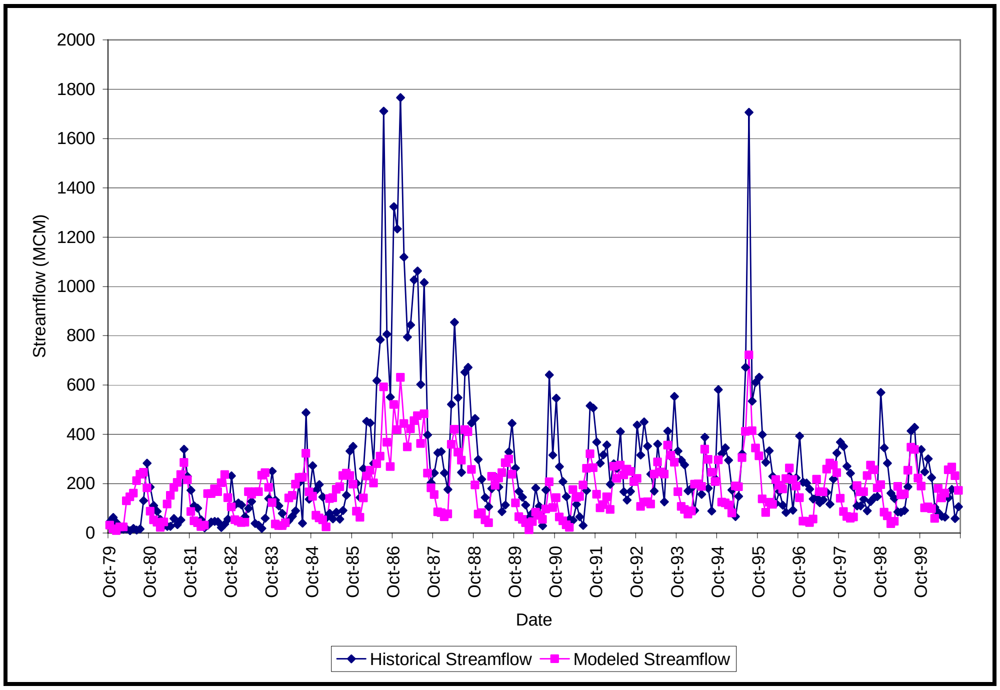

Figure 54: Ft Quitman Monthly Streamflow Comparison

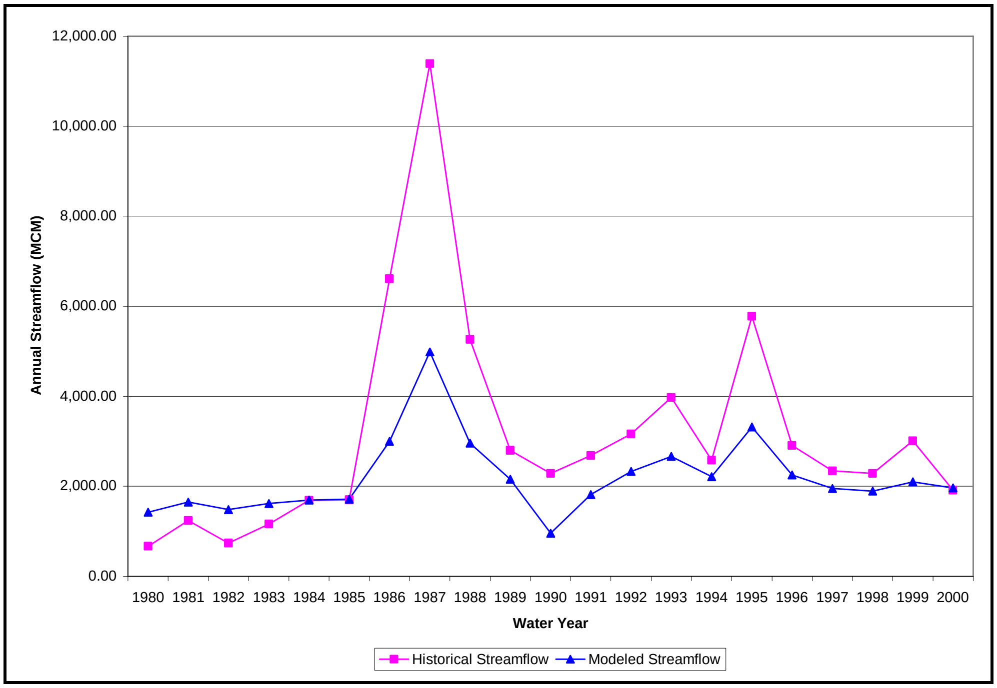

Figure 55: Ft Quitman Annual Streamflow Comparison

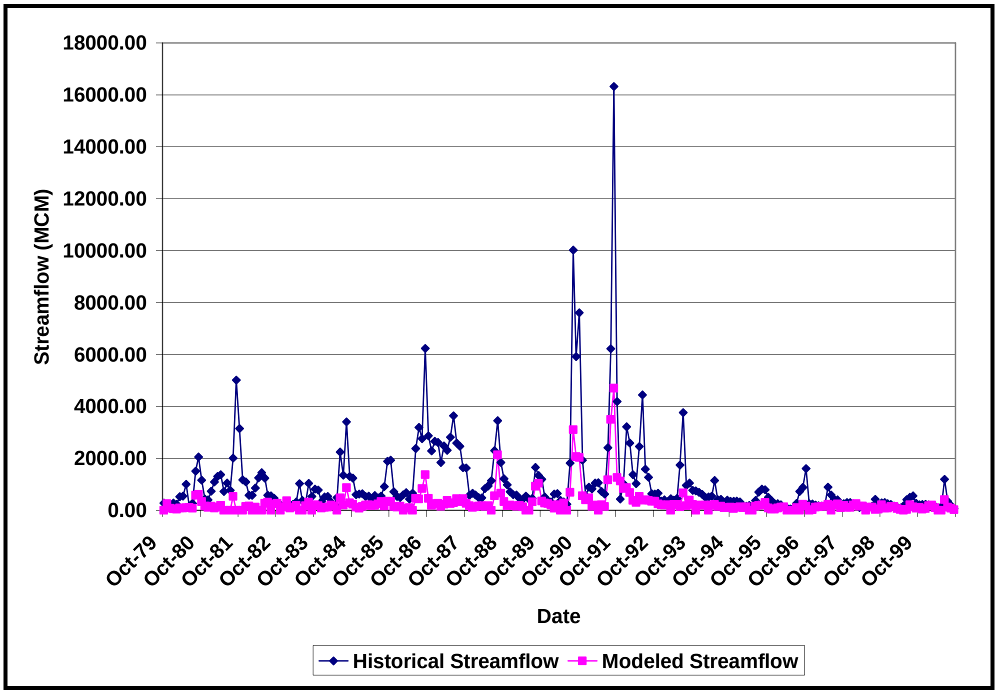

Figure 56: Ojinaga Monthly Streamflow Comparison

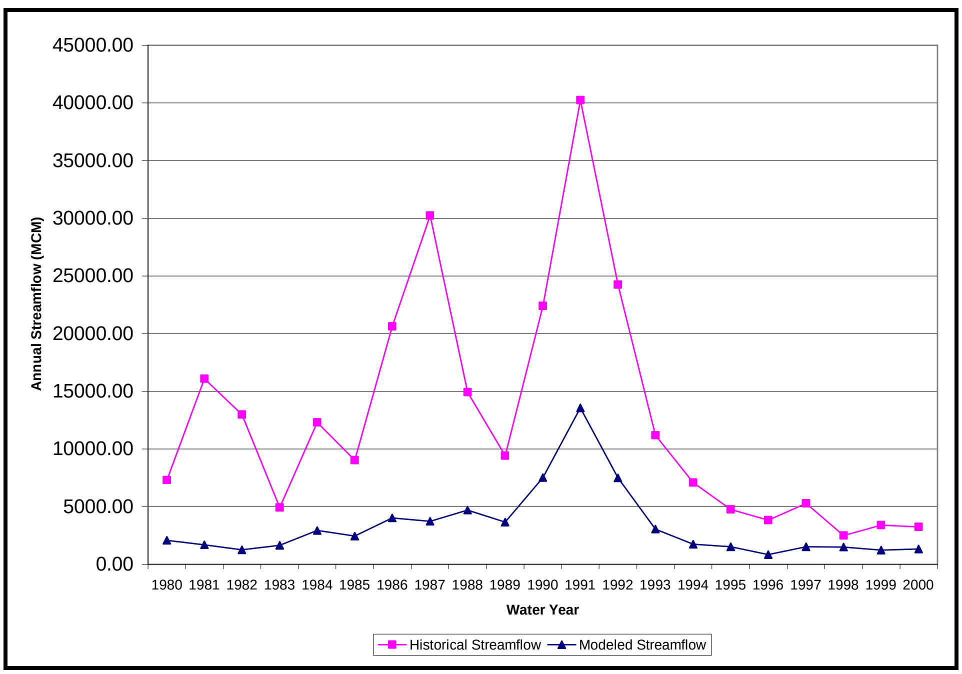

Figure 57: Ojinaga Annual Streamflow Comparison

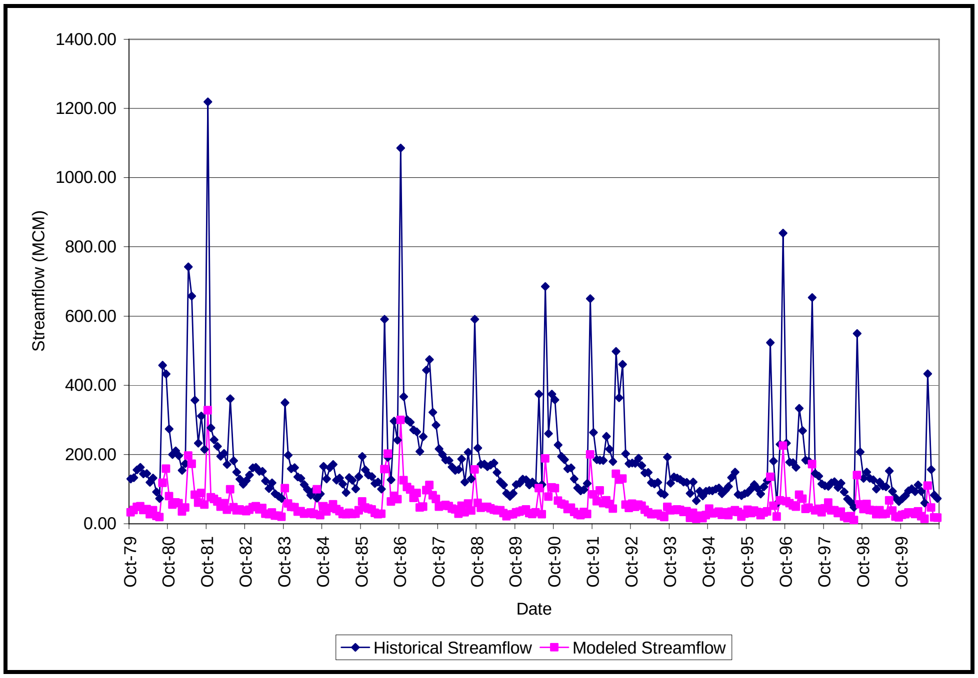

Figure 58: Pecos Monthly Streamflow Comparison

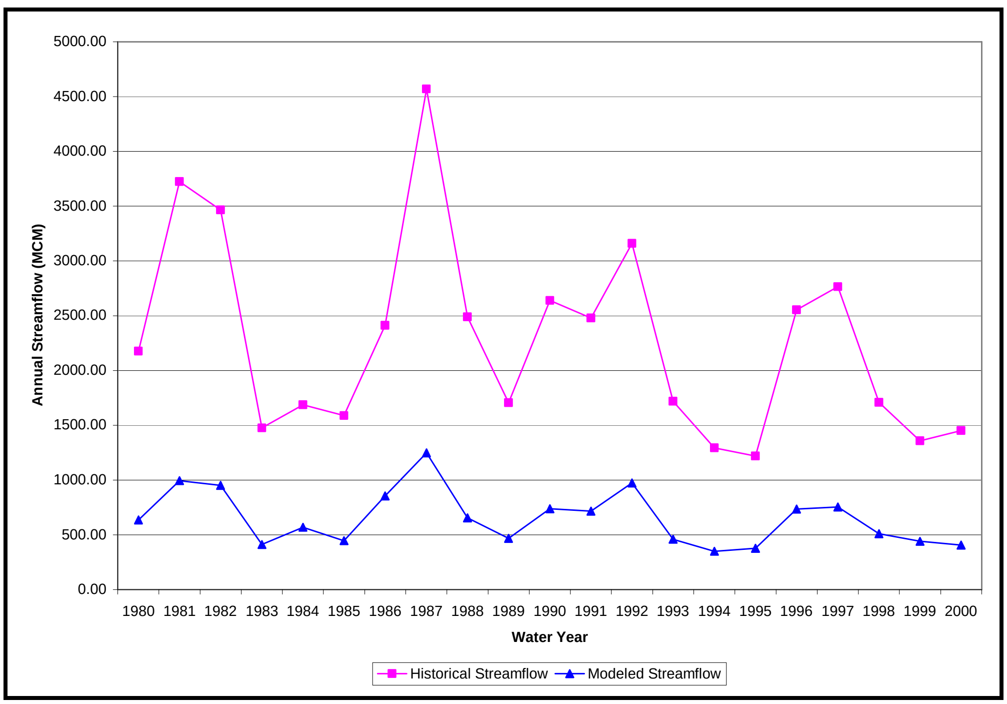

Figure 59: Pecos Annual Streamflow Comparison

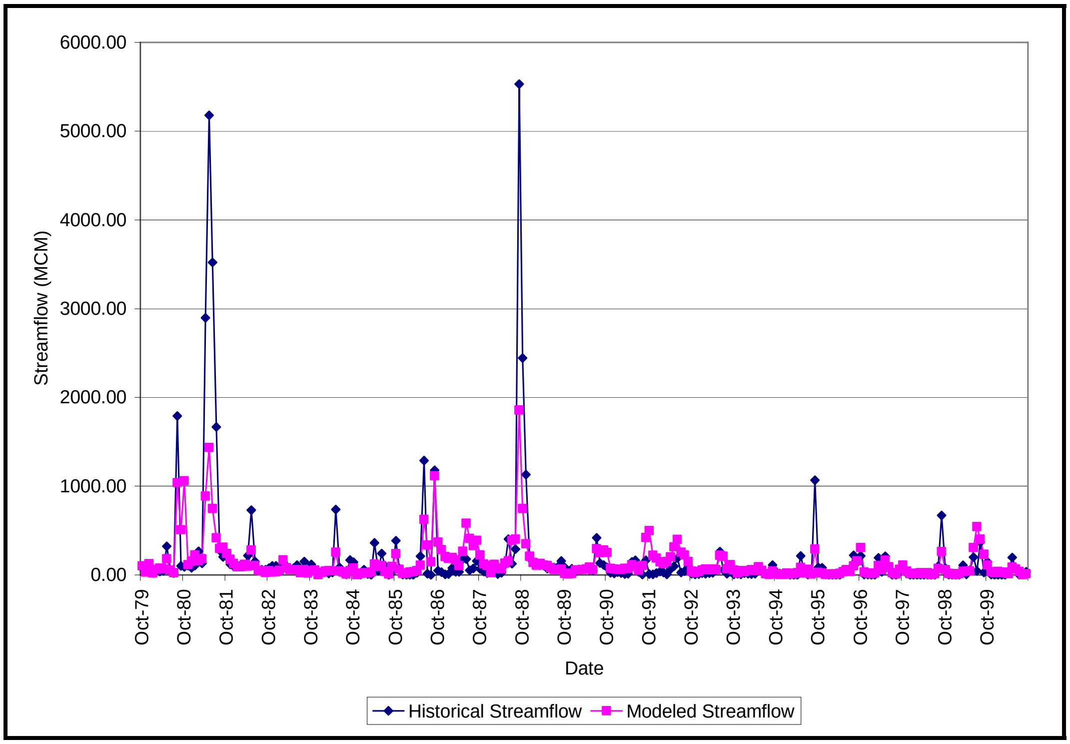

Figure 60: Rio Salado Monthly Streamflow Comparison

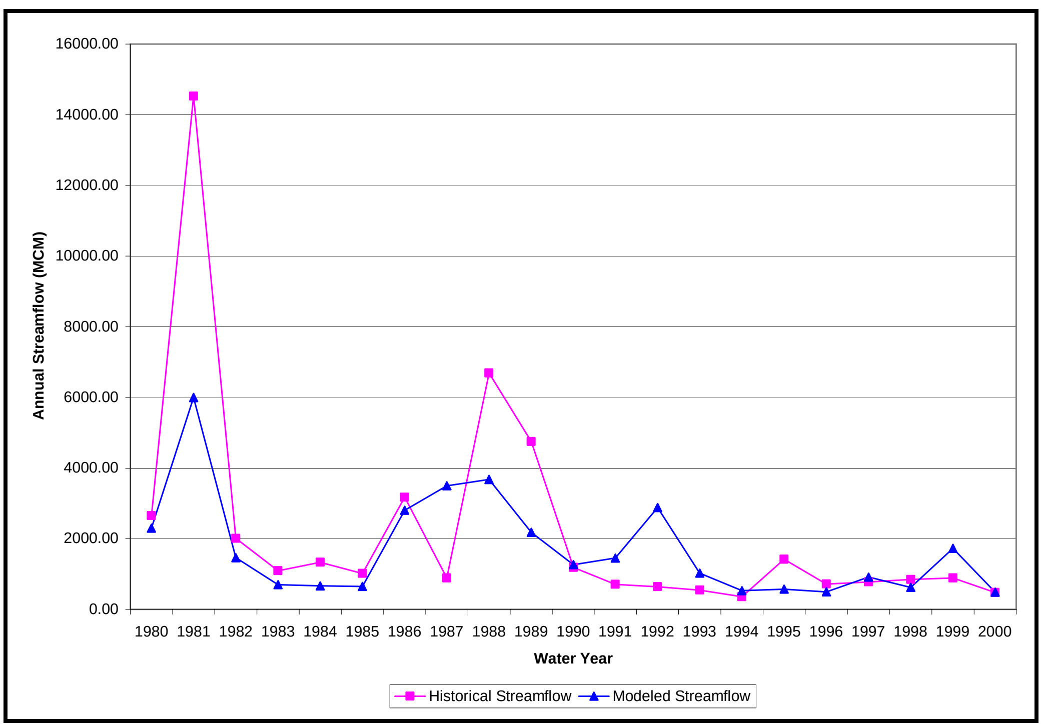

Figure 61: Rio Salado Annual Streamflow Comparison

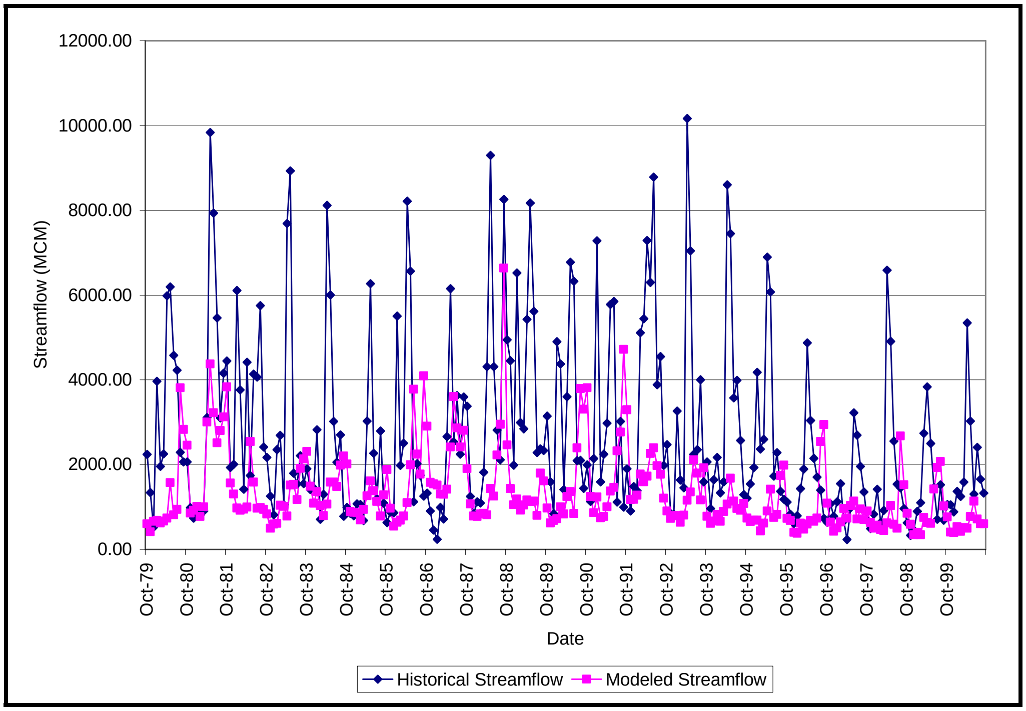

Figure 62: Rio Grande City Monthly Streamflow Comparison

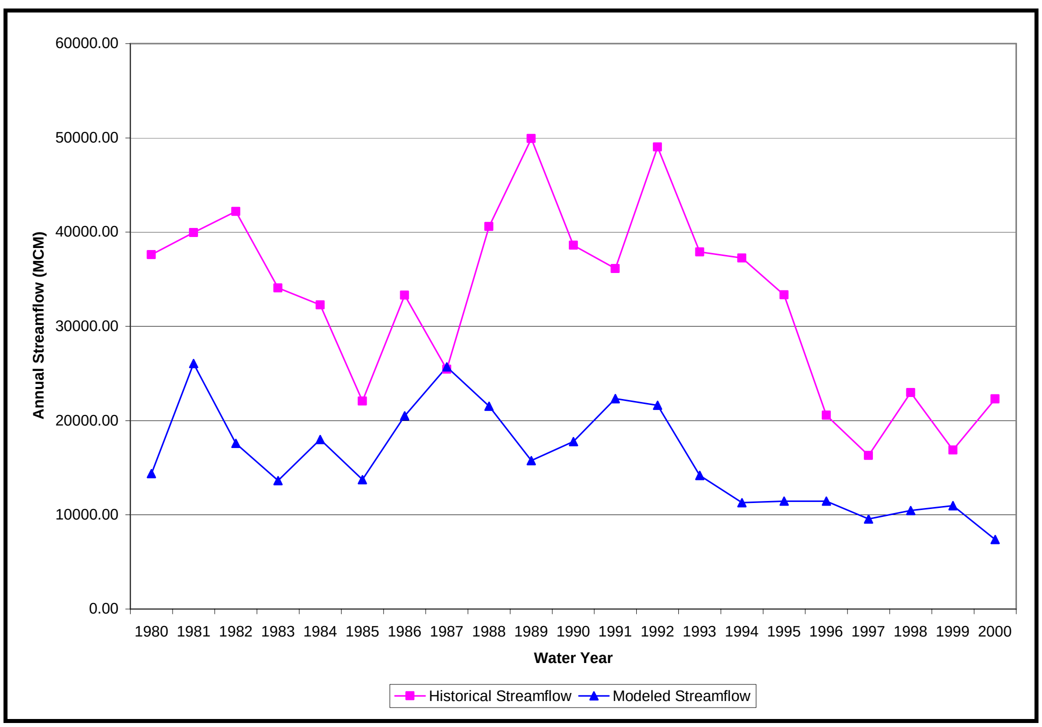

Figure 63: Rio Grande City Annual Monthly Streamflow Comparison

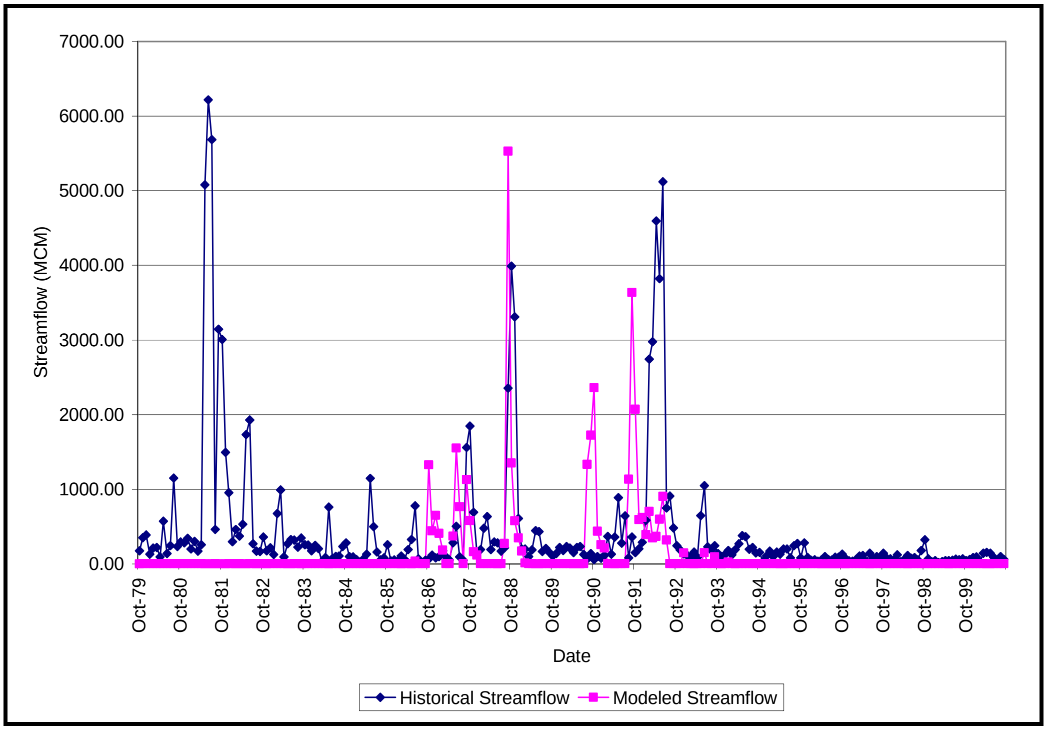

Figure 64: Brownsville Monthly Streamflow Comparison

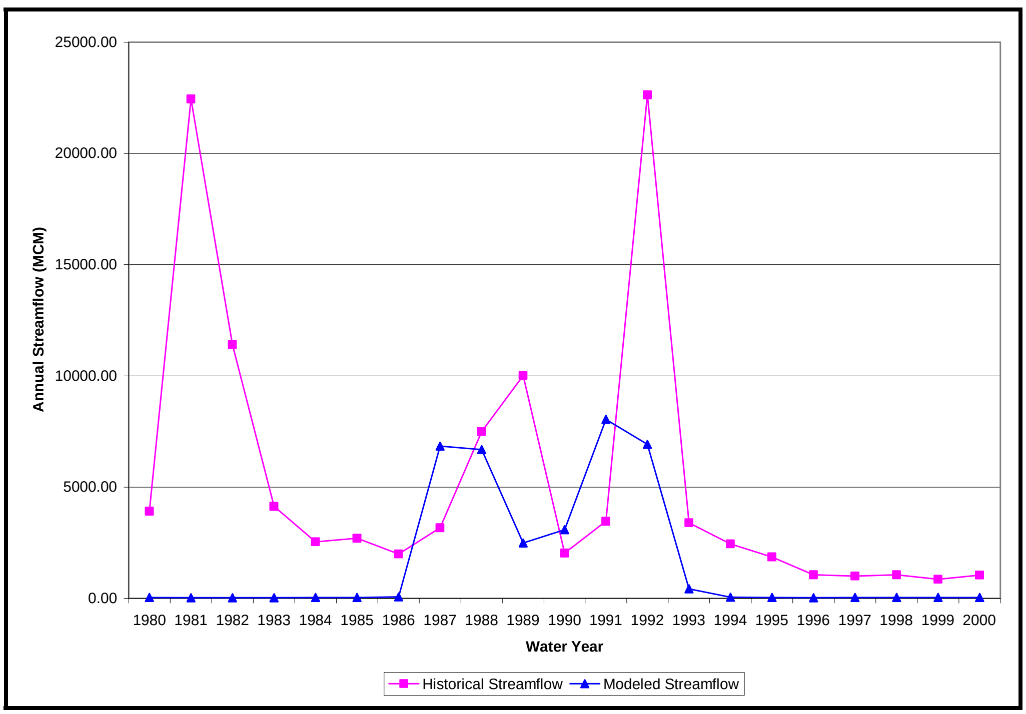

Figure 65: Brownsville Annual Streamflow Comparison

Appendix O. Error Messages - Failure

Scenario	Year	Month	Branch	Message
Current Accounts	1980	May		Failure to solve in month 5, year 1980. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 5, total iterations for this month 7')
Historical Run	1980		Demand Sites\DR 025 Bajo Rio Bravo	WARNING: Not all the inflow to "DR 025 Bajo Rio Bravo" is consumed but there are not any return flow links to carry away the wastewater. You probably need to create return flow links. Double-click this message to go to this variable in the Data View.
Historical Run	1982	July		Failure to solve in month 7, year 1982. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 6, total iterations for this month 7')
Historical Run	1982	August		Failure to solve in month 8, year 1982. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 6, total iterations for this month 7')
Historical Run	1983	March		Failure to solve in month 3, year 1983. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 4, total iterations for this month 5')
Historical Run	1983	April		Failure to solve in month 4, year 1983. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 7, total iterations for this month 8')
Historical Run	1984	April		Failure to solve in month 4, year 1984. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 8, total iterations for this month 9')
Historical Run	1984	July		Failure to solve in month 7, year 1984. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 6, total iterations for this month 7')
Historical Run	1984	August		Failure to solve in month 8, year 1984. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 4, total iterations for this month 5')
Historical Run	1985	April		Failure to solve in month 4, year 1985. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 6, total iterations for this month 7')
Historical Run	1985	July		Failure to solve in month 7, year 1985. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 6, total iterations for this month 7')
Historical Run	1985	August		Failure to solve in month 8, year 1985. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 6, total iterations for this month 7')
Historical Run	1986	Februa		Failure to solve in month 2, year 1986. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 2, total iterations for this month 3')
Historical Run	1986	April		Failure to solve in month 4, year 1986. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 7, total iterations for this month 8')
Historical Run	1986	August		Failure to solve in month 8, year 1986. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 6, total iterations for this month 7')
Historical Run	1989	May		Failure to solve in month 5, year 1989. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 8, total iterations for this month 10')
Historical Run	1989	June		Failure to solve in month 6, year 1989. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 5, total iterations for this month 7')
Historical Run	1990	April		Failure to solve in month 4, year 1990. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 3, total iterations for this month 5')
Historical Run	1990	June		Failure to solve in month 6, year 1990. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 5, total iterations for this month 7')
Historical Run	1991	April		Failure to solve in month 4, year 1991. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 9, total iterations for this month 10')
Historical Run	1993	Novem		Failure to solve in month 11, year 1993. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 2, total iterations for this month 3')
Historical Run	1993	March		Failure to solve in month 3, year 1993. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 5, total iterations for this month 6')
Historical Run	1994	March		Failure to solve in month 3, year 1994. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 6, total iterations for this month 7')
Historical Run	1995	April		Failure to solve in month 4, year 1995. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 7, total iterations for this month 8')
Historical Run	1995	May		Failure to solve in month 5, year 1995. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 6, total iterations for this month 9')
Historical Run	1996	Novem		Failure to solve in month 11, year 1996. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 1, total iterations for this month 2')
Historical Run	1996	April		Failure to solve in month 4, year 1996. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 4, total iterations for this month 6')
Historical Run	1996	May		Failure to solve in month 5, year 1996. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 6, total iterations for this month 8')
Historical Run	1996	June		Failure to solve in month 6, year 1996. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 2, total iterations for this month 4')
Historical Run	1996	August		Failure to solve in month 8, year 1996. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 2, total iterations for this month 4')
Historical Run	1997	June		Failure to solve in month 6, year 1997. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 4, total iterations for this month 7')
Historical Run	1998	May		Failure to solve in month 5, year 1998. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 5, total iterations for this month 6')
Historical Run	1999	May		Failure to solve in month 5, year 1999. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 5, total iterations for this month 8')
Historical Run	2000	April		Failure to solve in month 4, year 2000. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 3, total iterations for this month 4')
Historical Run	2000	May		Failure to solve in month 5, year 2000. Results not available for this month and may not be accurate in later months. . (Error Code = -2, ErrorNumber = 0, Error Message = 'Failed while solving allocation order 1, iteration 3, total iterations for this month 5')